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THESIS

EXPEDITIONARY OBLONG MEZZANINE
by
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This research explores how advanced collaboration tools might improve current operational environments within military and government organizations. Currently, military and government organizations collaborate via in-person communications and brief situational awareness using static and time-late information by sharing PowerPoint presentations. Two emerging technologies, the Emergency Operations Center in a Box (EOC in a Box) and Oblong Mezzanine, offer innovative methods to create a collaborative assessment environment, even in disadvantaged intermittent latency (DIL) environments. EOC in a Box offers rapid communications and networking infrastructure, and can be setup within hours of initial need. Oblong Mezzanine offers an advanced collaboration environment as seen in the movies *Minority Report* and *Iron Man* 3, where gestural accommodations enable new forms of collaboration with high definition graphics. Development in 2014 showed that these two capabilities could be married to create a rapidly deployable expeditionary capability to support nuanced and high-end collaboration, command and control, and data investigation.

The purpose of this thesis is to determine if the Oblong Mezzanine coupled with the EOC in a Box technology is useful in an emergent situation. This thesis examines Mezzanine-to-Mezzanine and Mezzanine-to-other collaborative appliances in low bandwidth and austere environments.

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EXPEDITIONARY OBLONG MEZZANINE

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	Three Dimensional
AD	Active Directory
AMP	Ampere
AOE	Application Operating Environment
AOR	Area of Responsibility
ATA	Advanced Technology Attachment
ATSC	Advanced Television Systems Committee
BTU	British Thermal Unit
BYOD	Bring Your Own Device
C2	Command and Control
C2IE	Command and Control Information Environment
C3	Command Control and Communications
CEO	Chief Executive Officer
COTS	Commercial of the Shelf
CMM	Collaboration Mission Manager
CUI	Command User Interface
DIL	Disadvantaged Intermittent Latency
DNS	Domain Name Servers
DOD	Department of Defense
DOS	Department of State
DVI	Digital Video Interface
EOC	Emergency Operations Center
FCC	Federal Communications Commission
FHA	Foreign Humanitarian Assistance
FLAK	Fly Away Kits
FPS	Frames Per Second
GIG	Global Information Grid
GUI	Graphical User Interface
GSA	General Service Administration
HADR	Humanitarian Assistance and Disaster Relief

HD	High Definition
HDTV	High Definition Television
HFN	Hastily Formed Network
HVAC	Heating Ventilation and Air Conditioning
IAAS	Infrastructure as a Service
ICMP	Internet Control Message Protocol
IP	Internet Protocol
IPSEC	Internet Protocol Security
ISA	Instruction Set Architecture
ISP	Internet Service Provider
ISR	Intelligence Surveillance and Reconnaissance
IT	Information Technology
JMAST	Joint Mobile Ashore Support Team
JP	Joint Publication
MB	Megabyte
Mb	Megabit
MBPS	Megabytes Per Second
Mbps	Megabits Per Second
MCTSSA	Marine Corps Tactical Systems Support Activity
MNCC	Multinational Command Center
MOC	Mobile Operations Center
MS	Milliseconds
NAT	Network Address Translation
NEMA	National Electrical Manufacturer Association
NGO	Non-Governmental Organizations
OFDA	Office of Foreign Disaster Assistance
OODA	Observe Orient Decide and Act
OS	Operating System
OSI	Open Systems Interconnection
OS X	Operating System Ten
PDU	Power Distribution Unit
POE	Power Over Ethernet

SAAS	Software as a Service
SAN	Storage Attached Network
SATA	Serial Advanced Technology Attachment
SB2	Surfbeam 2
SLA	Service Level Agreement
SDK	Software Development Kit
SDTV	Standard Definition Television
SNR	Signal-to-Noise Ratio
TB	Terabyte
TED	Technology Entertainment Design
UPS	Uninterruptable Power Supply
USN	United States Navy
USPACOM	United States Pacific Command
VDI	Virtual Desktop Infrastructure
VLAN	Virtual Local Area Network
VPN	Virtual Private Network
VTC	Video Teleconference
VM	Virtual Machine
VMM	Virtual Machine Manager
WI-FI	Wireless Fidelity

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I. INTRODUCTION

The primary tools of any successful decision maker are collaboration and effective distribution of information. Today, the nature of both is evolving. Exchanges that once involved co-located sessions using static data have transformed into global platforms where people separated by oceans can use myriad of data ingests, which is defined as inputs into the system such as streaming video, Internet pages, video teleconferences, and other data feeds.

This phenomenon is only increasing with the advances in enterprise architecture (EA) and big data, providing enormous amounts of data instantaneously available to both collaborators and decision makers. In many cases, the decision makers and actors are geographically separated, and working in austere environments. Often decisions markers make judgments based on enormous amounts of data. Any leader—whether a chief executive officer (CEO) for a Fortune 500 company or a military commander—relies on teams of personnel to decipher data and provide real-time, intelligent, and actionable solutions to problems. This thesis seeks to understand how advanced collaboration systems can improve command and control (C2) in austere environments by bridging human and computer interaction (HCI). This study will examine how the Oblong Mezzanine collaborative communication system could potentially fill the ever-increasing requirement to collaborate with multiple domestic and international groups during times of need and in austere environments.

The United States responds to humanitarian and disaster relief (HADR) conditions to help countries prepare, respond and recover from crisis (General Service Administration, 2014). In a Congressional Research Service report, Rhoda Margesson (2015), a specialist in international humanitarian policy, asserts that coordination of effort presents a significant challenge, often resulting in duplication of effort among numerous agencies and international actors. Margesson concludes that effective collaboration mechanisms are needed to support organizations arriving to assist in times of crisis.

A. NEXT-GENERATION COLLABORATION

Next-generation collaboration is defined as systems merging visual collaboration technology, social media, and cloud-based content with traditional theories of collaboration. Traditionally, working groups were forced to use either synchronous or asynchronous models of collaboration, both of which were one-dimensional and time delayed. With next-generation technologies, organizations can shift from tele-collaboration methods to information-presence methods. Oblong Industries designed a next-generation platform to provide active interaction among all participants in collaboration sessions by bridging people, information, and technology.

1. Oblong Mezzanine

The Oblong Mezzanine collaboration system is a uniquely designed collaborative, multi-user, and multi-device system that allows disparate people to share screens, devices, applications, data, and thoughts in a single workspace environment using spatial technology (Oblong Industries, 2014a). For example, while utilizing a Mezzanine system in a single system configuration allows the connection of four inputs local via digital video interface (DVI) connections and four inputs via wireless connections (Oblong Industries, 2014a). These connections can be controlled, manipulated, and shared via a spatially aware wand. When connected to three or more Mezzanines, the system creates one seamless experience by inter-connecting all four systems into a single session. Figure 1 depicts the Oblong Industries Mezzanine system located at Naval Postgraduate School in Monterey, California.

Figure 1. Photograph of the NPS Mezzanine Systems

2. Emergency Operations Center in a Box

The Emergency Operations Center in a box (EOC in a Box) is a platform designed in 2011 at the Naval Postgraduate School (NPS) in Monterey, California. The platform supports hastily formed networks (HFN), and provides cloud-based infrastructure utilizing virtual machine technology (VM). EOC in a Box is a lightweight, easily deployable platform that can provide rapid communications in austere environments. EOC in a Box is a pre-configured, pre-built, and ready to deploy HFN, capable of providing infrastructure as a service (IaaS) and software as a service (SaaS) cloud computing technologies. IaaS is a way of providing computing services such as servers, storage, and network equipment services (Mell & Grance, 2009). SaaS is a means of providing software and applications as an on-demand service (Mell & Grance, 2009).

3. EOC in a Box and Mezzanine Working Together

Combining the Mezzanine system with the EOC in a Box allows communication teams the ability to provide more effective C2 by enabling real-time collaboration. The EOC in a Box provides an HFN, which provides an infrastructure to connect multiple local workstations via DVI or WI-FI, and remote data ingests via the Internet. This connectivity provides forward operating units dynamic near real-time information, and a collaborative assessment environment.

4. Potential Use Cases

Combining advanced collaborative technology, such as the Oblong Mezzanine with an EOC in a Box allows organizations to operate in austere environments without sacrificing C2 capabilities and requirements. Potential situations include the following:

- HADR: providing emergency command control and communications between ground forces, naval assets, disaster relief centers, and multinational command centers (MNCCs).
- Expeditionary: missions requiring lightweight C3 requirements.

B. TECHNICAL ISSUES

It is not known how well the Mezzanine system works in bandwidth-limited environments. An Oblong Industries sales engineer, Pete Lockard, stated that for a successful high definition (HD) session the Mezzanine system requires 15 megabyte (MB) of dedicated bandwidth (P. Lockard, personal communications, July 6, 2015). However, Lockard did not state if the system would function under lower bandwidth constraints. In most cases, when working in austere environments the need for HD quality full motion video will be rare. This thesis explores the technical issues when working with small, lightweight expeditionary satellite communication assets.

C. ASSUMPTIONS

Since the focus of this thesis is on the technical issues of using commercial off the shelf (COTS) collaboration systems in austere working environments, a certain level of understanding is assumed. Based on this logic, the bounding assumptions are

- Oblong Mezzanine will help collaboration efforts amongst all participants.
- Technicians have the appropriate training on both the EOC in Box and Mezzanine equipment to operate them correctly.
- Human factors among collaboration participants in both hierarchical and non-hierarchical relationships will have credibility and trust.

D. RESEARCH QUESTIONS

The following questions are explored in this research:

1. How can the Oblong Mezzanine advanced collaboration system be used to provide effective Command and Control in austere environments?
2. Given the Oblong Mezzanine capability, what factors need to be considered before deploying into an austere environment? Specifically, this thesis will address the following:

- **Bandwidth:** Does the Ka band system have sufficient bandwidth for Mezzanine-to-Mezzanine or Mezzanine to other equipment interoperability?
- **Latency:** Does Satellite latency degrade the user experience?
- **Virtual private network (VPN) overhead:** Does the increased packet size of VPN and encryption affect usability in austere environments?
- **Weight:** Is the current weight of the Mezzanine system facilitate expeditionary logistics?

3. What possible future mission(s) does Oblong Mezzanine enable?

E. BENEFITS

Application integration is the process of assimilating data and functions of one application to another. This integration has become more difficult due to increased data and security requirements. Additionally, in many cases, both government and civilian organizations collaborate on data ingested from multiple domains, with multiple security levels, from a host of mission-centric applications while operating in austere environments. Oblong Mezzanine can assist organizations in transitioning from time-late static presentations to near real-time collaboration assessments.

Explaining the mechanics of the Oblong Mezzanine system, Naval Postgraduate School (NPS) Lecturer Albert Barreto describes the Mezzanine system as technology designed to address collaboration roadblocks by integrating information directly on the screen at the pixel level (A. Barreto, personal communication, 29 September 2015). It is not a substitute for data integration, but enables a solid foundation for collaboration, and allows users to integrate the results of multiple applications from multiple enclaves never designed to work together. The integration of information delivers the potential for dynamic interactions incorporating numerous data feeds into a single collaboration session, and provides the ability for multiple people to manipulate and discuss the data at one time. According to Barreto, while the data being captured is analyzed and fused together outside the application operating environment (AOE), near real-time information is presented and manipulated in the AOE by all the collaboration session participants (A. Barreto, personal communication, September 29, 2015).

F. THESIS ORGANIZATION

Chapter II provides an overview of the information environment and distributed collaboration concepts. It will describe the Oblong Mezzanine system and the EOC in a Box architecture for providing services and connectivity to the tactical edge of the global information grid (GIG). It will also discuss applicable concepts related to the command and control information environment (C2IE), knowledge management, and humanitarian assistance and disaster relief (HA/DR).

Chapter III describes the methodology used to conduct the study. Three evaluations were conducted; in Evaluation One, researchers witnessed a Mezzanine-to-Mezzanine session by Oblong Industries; in Evaluation Two, the researchers conducted a test session between the expeditionary Mezzanine and workstations connected to the EOC in a Box; and in Evaluation Three, researchers determined the power consumption and weight characteristics of the expeditionary Mezzanine.

Chapter IV provides the analysis and application of all the data gathered during the evaluations and research process. It combines the concepts in the previous chapters, and analyzes and presents recommended practices for the Mezzanine system combined with the EOC in a Box architecture to support collaboration in austere environments.

Chapter V provides conclusions on the results, proposes potential uses for the Oblong Mezzanine system, and makes recommendations for future research.

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II. LITERATURE REVIEW

A. BACKGROUND

The United States Government Accountability Office (GAO) (2005) defines collaboration as a cooperative activity that yields more value than any one person does or organization could produce alone. This definition suggests the importance of being able to collaborate effectively among many partners and produce valued outcomes. This is important when working in austere environments such as operating in expeditionary combat actions or assisting in HADR operations. Co-located collaboration can be extremely valuable during complex analytical tasks. However, many organizations have geographically separated organizational structures requiring distributed collaboration methods. Michelle Fong (2004) identifies two methods of virtual collaboration:

- Synchronous: modes of communication using technologies such as video teleconferencing (VTC) systems or software such as NetMeeting or other collaborative toolkits.
- Asynchronous: mode of communication designed for dispersed groups, usually designed around email, discussion boards, or even plain old bulletin boards (p. 6).

Whether supporting military operations or operations supporting HADR, commanders' main objectives and operational necessities are to author strict and precise command, control, and communications (C3) of operations in two complex and distinctive environments: physical and informational. Both the physical and informational environments affect operations and sustainment within the air, land, maritime, and space domains. The physical environment, according to Joint Publication (JP) 3–0, Joint Operations, includes terrain, weather, topology, and other environmental conditions, and supporting infrastructure (Department of Defense, 2011). Factors involving this environment will determine the characteristics of the working environment to include shelter, power, and availability of local telecommunications to support operations. JP 3–0 describes the information environment as being "composed of people, organizations, and systems that collect process, disseminate, or act on information" (Department of Defense, 2011 p. IV-2). According to the JP 3–32, command and control for joint operations, effective C3 is the product of successful collaboration that relies on a multifaceted architecture involving people, procedures, equipment, and the effective communication of orders and objectives.

In many cases, organizations are operating in austere environments throughout the world supporting both military and HADR operations. Operating in austere environments presents many challenges: number of stakeholders, urgency, and lack of communication assets. These obstacles often stifle information exchange, leading to poor collaboration and eventual loss of operational control of the environment.

To stay at the forefront of military operations, the United States Navy (USN), other military forces, and civilian organizations require near real-time information from multiple sources. The Mezzanine system introduced by Oblong Industries has the potential to be a platform to bridge disparate organizations and teams into a single collaborative environment when combined with an emergency operations center.

The Mezzanine system has the capability to enrich C2 functions by creating a collaboration session not bounded by software or hardware architectures. Oblong Industries describes the Mezzanine system as the only truly collaborative system on the market that provides a rich human and computer interface (HCI) allowing people to actively interact during collaborative sessions (Oblong Industries, 2014a). Given this claim, this thesis study aims to examine this statement.

This research evaluates the Oblong Mezzanine, an emerging advanced collaboration system, coupled with NPS's EOC in a Box, an expeditionary communication system that a provides cloud-computing architecture ability which incorporates disparate organizations and operational products over reduced bandwidth communication equipment while operating in austere environments. These evaluations are based on qualitative and quantitative data measuring latency, packet loss, and picture quality.

B. INFORMATION ENVIRONMENT

Organizing operations involves a multitude of considerations, including unifying the administrative and operational processes to help control required actions. Understanding the information environment helps commanders recognize factors that may affect decisions.

1. Definition

The *information environment* is a steadily growing conceptual space capturing the advancement of technology in the global information grid (GIG) composed of people, organizations (including commercial, governmental) and connected systems, collecting, processing, disseminating, or acting on information (Department of Defense, 2011). Army General Martin Dempsey summed up its importance in his white paper for the Joint Information Environment.

> There is no better example of the challenge ahead than that of the information environment. From moving supplies in the wake of a hurricane disaster to ordering troops to the Pacific, or addressing the ever-changing cyber threat, the global dependence on information and networks in everyday activities demands our attention now (Dempsey, 2013, p. 3).

The JP 3–0 describes the information environment as the time and place where people and automated systems observe, orient, decide, and act (OODA) on data and information, and therefore, is the chief mechanism for precise decision making (Department of Defense, 2011). In today’s cutting-edge environment, vast amounts of information are readily available for leaders to operate continuously in the OODA loop. However, with advanced technology and big data comes an increased need for collaboration mission managers (CMM) to decipher data ingests and provide managers with near real-time and accurate information required for rapid decision making.

2. Distributed Collaboration

In most cases, the most common, effective and efficient process for people to collaborate is via co-located communication. However, with the current advances in technology, and an ever-growing need to globalize, organizational structures have become more distributed.

The practice of non-co-located *collaboration* has progressively grown in attractiveness within both the government and commercial sector. The generally accepted definition of collaboration is to enable an intellectual endeavor through the sharing of knowledge, learning, and the building of consensus (Collaboration, n.d.). The term *distributed collaboration* is somewhat new and can be considered the latest advancement in working within the information environment. Distributed collaboration is actively coordinating collaboration efforts involving numerous personnel at multiple sites using various computing technologies.

The computing environment is unable to capture the importance of space and human interactions. In the last decade, distributed collaboration was enabled by phone, chat, Email, and with video teleconferencing (VTC). While those practices prove effective between people and organizations that routinely practice using these channels, they have significant problems for ad hoc and tactical communications, where the participants are not trained in these communication practices. The Mezzanine system aims to address these shortcomings by providing a means for interactive group discussion, and allowing the simultaneous use of organic material such as PowerPoint, discussion boards, and/or live video.

a. Responding to Crisis

When directed by higher authority, the United States military responds to worldwide natural disasters and delivers humanitarian assistance to those in need at the request of the Department of State (DoS). The Asian-Pacific region is home to 36 countries and half the world's population. Unfortunately, this area of operations (AOR) is highly prone to natural disasters ranging from earthquakes and typhoons to flooding and mudslides. This region is home to the U.S. Pacific Command (USPACOM), which executes its mission covering more than 100 million square miles, most over water and in poverty-stricken areas.

Establishing communication and collaboration efforts after any natural disaster or during a humanitarian assistance mission is extraordinarily challenging. According to Christian Gutierrez (2013), lessons learned collected from past HADR efforts revealed challenges establishing mobile communication systems and forming accurate situational awareness of the affected area. Gutierrez adds that this perpetuates information challenges between the United States, foreign military, government relief agencies, and non-governmental agencies (NGOs) to accurately access requirements and needs. Alan Larson, under secretary for Business and Agricultural Affairs, Department of State, during a congressional hearing for the tsunami response on December 26, 2004, asserts even though adequate coordination was witnessed between the United Nations (UN) and other agencies a more robust command, control, and coordination system is required to help coordinate relief efforts (Tsunami Response, 2005). The Mezzanine system has the potential to provide a tool for all organizations to track and coordinate relief efforts. Even though technology and open source coding, such as the extensible markup language (XML) based standards have advanced dramatically, there is still a need to advance inter-organizational collaboration (Horan & Schooley, 2007). The Mezzanine system can ingest multiple data types since the system works at the pixel level, not a strictly defined data level. Since pixels do not add any impact to the system, the Mezzanine system can incorporate almost any data format, including foreign Unicode characters, where most software applications start to fail (Oblong Industries, 2014a).

Gutierrez (2013) further explains key areas where HFN and COTS software can help provide needed C3 among first responders, key governmental and NGO agencies during relief efforts. For the purpose of this thesis, three key areas will be discussed where advanced collaboration systems can help. These areas are information sharing, interoperability, and C2. In a review of several incidents involving HADR efforts, Amy Donahue, associate professor at the University of Connecticut, and Robert Touhy, vice president for Strategic Planning at Hicks and Associates, Inc., argue that agencies continually have problems with command control and coordination (Donahue & Tuohy, 2006). Table 1 lists the difficulties identified in after action reports (AAR) during major events.

Table 1. Lessons Learned Identified by Crisis

Lessons Learned Issues	Anthrax Attacks	Columbia Recovery	Columbine	Hurricane Katrina	Oklahoma City Bombing	SARS	September 11th	Sniper Investigation
Communications			•	•	•		•	•
Leadership	•	•	•	•	•	•	•	•
Logistics	•	•		•	•	•	•	
Mental Health					•		•	•
Planning	•	•	•	•	•	•	•	•
Public Relations	•	•	•	•	•	•	•	•
Operations		•	•	•	•	•	•	•
Resource Management	•	•	•	•	•	•	•	•
Training & Exercises	•	•	•	•	•		•	

Source: Donahue, A. K. & Touhy, R. V. 2006. Lessons we don't learn: A study of the lessons of disasters, why we repeat them, and how we can learn from them. *Homeland Security Affairs, II*(2).

Moreover, these incidents were domestic events, where language differences and infrastructure deficiencies are minimal. International HADR events are more replete with these challenges. Responders are continuously re-learning the same lessons, and many responders have stated they will witness problems in these areas prior to a crisis (Donahue & Tuohy, 2006). There is a high probability that by employing an HFN network such as the EOC in a Box coupled with a Mezzanine system, these problem areas can be greatly minimized and possibly eradicated over time.

3. Information Sharing

Lesson learned indicate that the sharing of information between U.S. government agencies, foreign government agencies, NGOs, and others is many times ineffective. Ineffective communication and information sharing results in wasted resources and loss of critical time. Use of advanced collaboration systems, such as the Mezzanine, has the potential to foster information sharing and management among all participants. Effective communication mechanisms allow organizations to see their relevant information employed during collaboration, resulting in increased trust among participants.

4. Interoperability

More programs and processes that support interoperability are needed. Once trust is developed between participants, information will be more freely shared resulting in better cooperation and receptiveness. History shows there are a wide variety of communication systems (hardware and software) and data used by multiple organizations, and at times in varying languages (Gutierrez, 2013). Furthermore, most of these systems will not be interoperable based on their program languages creating highly fragmented and isolated C2 centers (Gutierrez, 2013). Establishing highly interoperable HFN networks with embedded advanced collaboration tools not restricted by program language, such as the Mezzanine, can quickly provide a solution for interoperability.

5. Command and Control

As stated previously, effective C2 procedures and architectures are cornerstones for successful collaboration. However, according to Dr. Peter Denning, Chair of the Computer Science Department at NPS, successful HFN networks need to be more decentralized in nature (Denning, 2006). This has the potential to create C2 problems for military organizations that are more used to hierarchical command structures. However, the establishment of decentralized command and control increases information sharing and interoperability between supporting agencies.

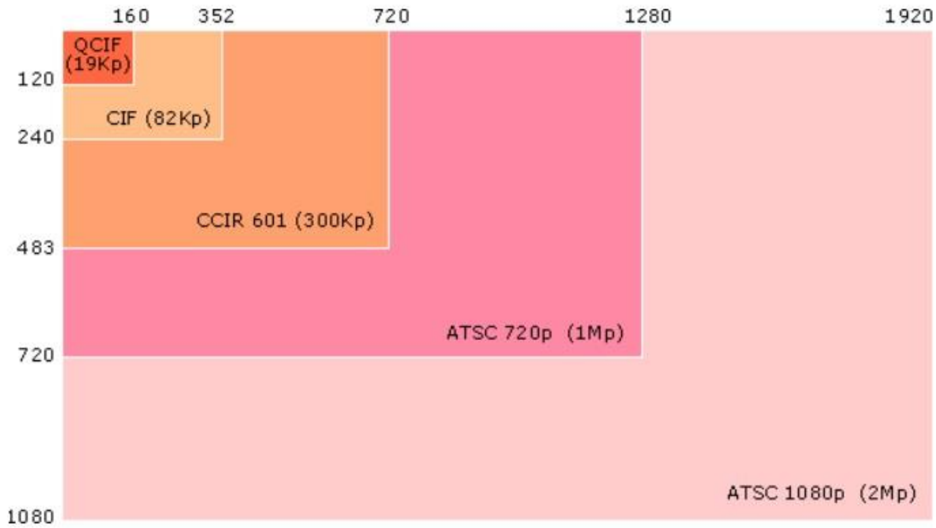
C. BASELINE MEASUREMENTS AND PERFORMANCE STANDARDS

To properly measure performance levels for the Mezzanine system, various reports and literature from the field will be used. The data collected were used to improve the level of reality and believability of the experiments, which support this thesis.

1. Video Streaming Performance Measurements

The Advanced Television Systems Committee (ATSC) determines the television (TV) standards to include high definition TV (HDTV), standard definition TV (SDTV), data, multichannel, and satellite based broadcasts (Advanced Television Systems Committee, 2007). ATSC (2007) defines the frame size of HD as having a resolution of 1280x720 or 1920x1080, and standard resolution as 480x64. It is important to understand, especially working in low-bandwidth environments, that as frame size increases, the requirements for processing the video content increase. Figure 2 is a chart illustrating various screen resolutions.

Figure 2. Chart Illustrating Common Resolution Sizes



Source: Waggoner, B. (2004). Understanding HD formats. Retrieved from Microsoft Corporation https://www.microsoft.com/windows /windowsmedia/howto/articles/understandinghdformats.aspx

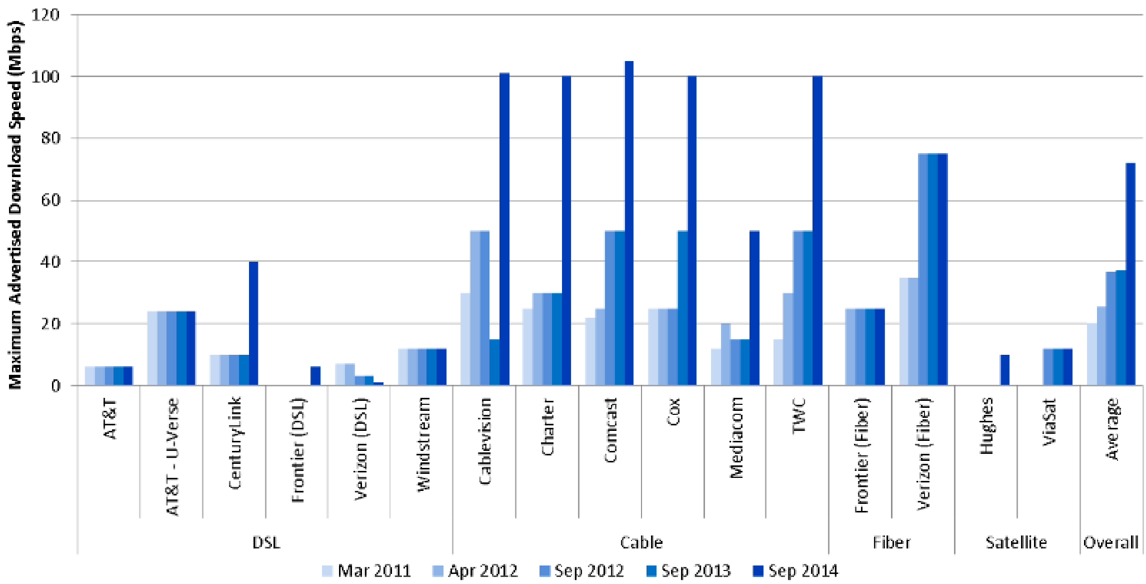
The Federal Communications Commission (FCC) (2016) stipulates in its broadband-speed guide that the minimum download speed to support HD video streaming is 4Mbps. The HD frame rates are 24, 25, 30, and 60 (Waggoner, 2004). The researchers will assume the meaning of minimum indicates the use of 1080x720p resolution at a frame rate of 24 frames per second (fps), which is the minimum HD quality resolution per multiple sources. The frame rates have a considerable impact on video quality, since a frame rate of 60fps requires more than two times the bandwidth than the frame rate of 24fps (Waggoner, 2004).

2. Broadband Service Provider Performance

Average performance data was derived from the FCC's report on fixed broadband service providers. The researchers will use this data to support assumptions on average speeds and quality of service parameters while using the Mezzanine system connected to either a land-based or satellite-based service provider.

The FCC reports collected data by sampling residential customers using broadband Internet service providers (ISPs) which consisted of over 80% of the users in the marketplace, resulting in thousands of respondents (Federal Communications Commission [FCC], 2015). Several interesting measurements found in the study are relevant to this thesis. The first are the advertised speeds of the most common service providers. Figure 3 shows the maximum advertised download and upload speeds by ISP. This information will be used to assume an average speed a particular site will have during a Mezzanine session. Of note, the chart also indicates there are a few ISPs that will not be able to support the 15Mbps requirement to participate in an HD quality session.

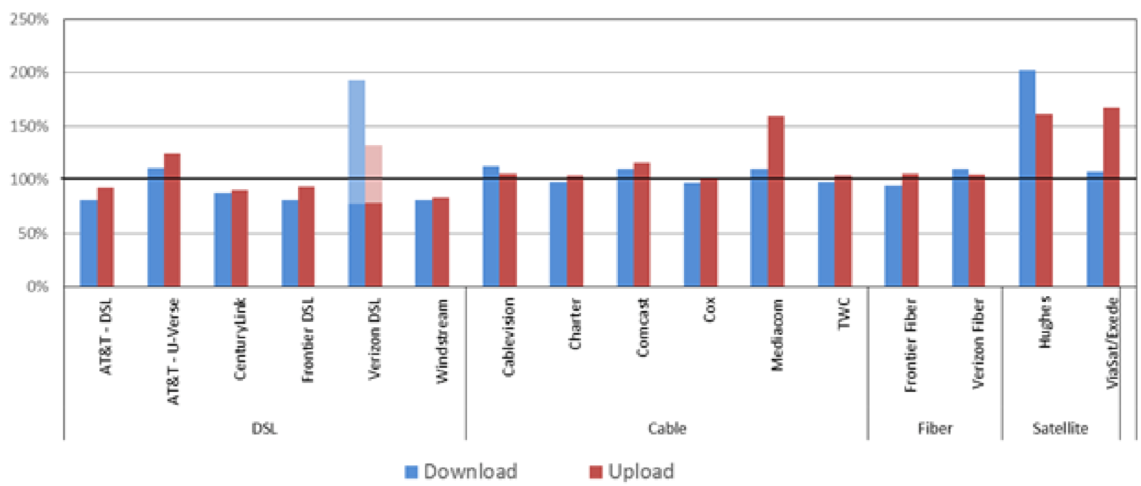
Figure 3. FCC Chart Showing Maximum Advertised Download Speed by ISP



Source: Federal Communications Commission (FCC). (2015). 2015 measuring broadband America fixed report. Retrieved from https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-broadband-america-2015#block-menu-block-4

Another key finding in the FCC's report is that most ISPs are averaging speeds above advertised levels. With this information, we can assume on average a site using fiber, DSL, or cable connection will have the necessary bandwidth to support a quality connection. Researchers assume operators will experience similar connection speeds indicated on FCC's report. This is good information when calculating the overhead associated with VPN and encryption algorithms. Additionally, communicators can rely on the advertised speeds of a particular provider vice assuming the advertised speeds are "up to" speeds that would be considered unattainable, especially during an emergency. Figure 4 is an illustration showing the ratio between advertised speeds and actual speeds witnessed by FCC.

Figure 4. FCC Chart Illustrating the Ratio of Actual Speed to Advertised Speed

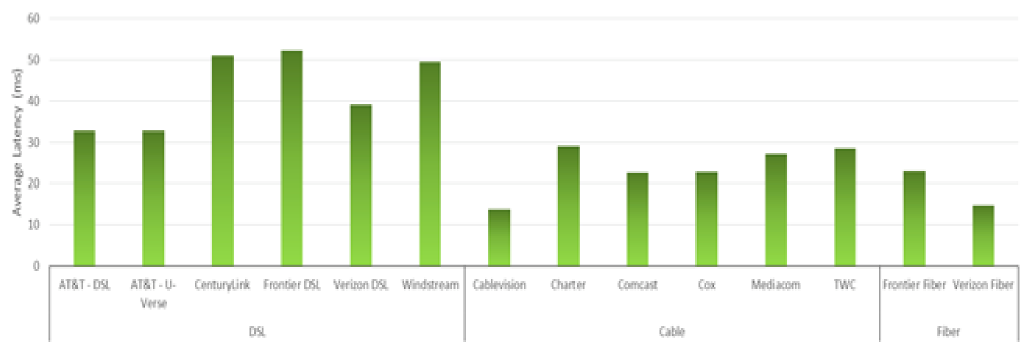


Source: Federal Communications Commission (FCC). (2015). Measuring broadband America fixed broadband report. Retrieved from https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-broadband-america-2015#block-menu-block-4

a. Latency

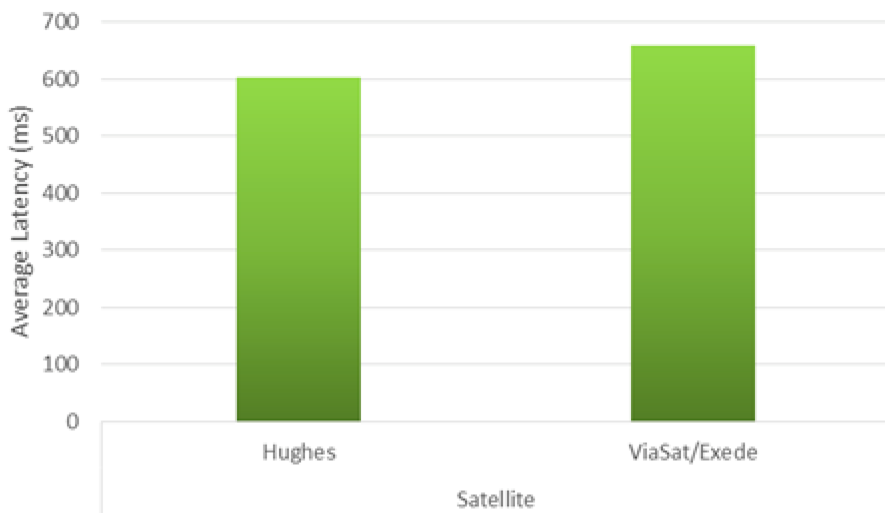
Latency is another measurement requiring consideration, especially when using satellite-based ISPs. Latency is the duration in seconds it takes for a data packet to travel from one node to another on a given network (FCC, 2015). The duration will increase as the distance of the data route grows, data congestion increases, and decreases as network speeds increase (FCC, 2015). Latency can be assumed nominal when connected to terrestrial land-based broadband services, which are usually below 100ms. However, latency becomes critical when using satellite-based services, which can be over 600ms. Figure 5 is an FCC chart illustrating average latency experienced during testing of the land-based ISPs. Figure 6 is an FCC chart showing latency experienced during testing of satellite-based ISPs.

Figure 5. Chart Illustrating Average Latency by Land-Based ISP



Source: Federal Communications Commission (FCC). (2015). Measuring Broadband America Fixed Broadband Report. Retrieved from https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-broadband-america-2015#block-menu-block-4

Figure 6. Chart Illustrating Average Latency for Satellite-Band ISP



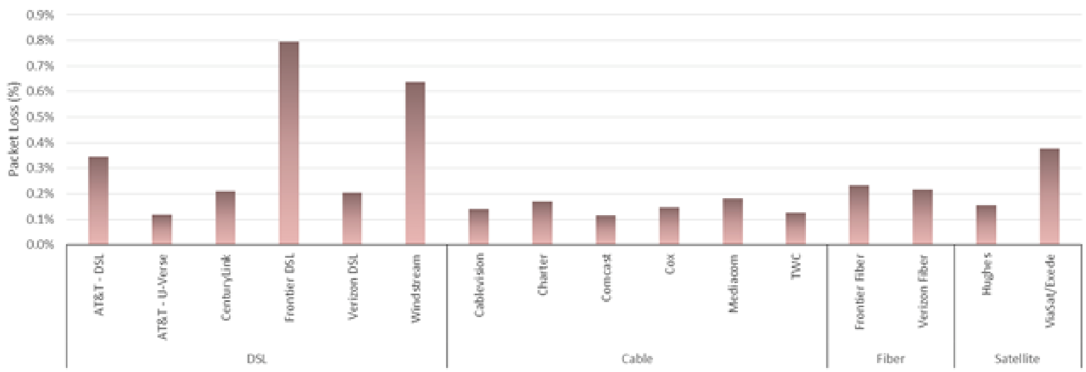
Source: Federal Communications Commission (FCC). (2015). Measuring Broadband America Fixed Broadband Report. Retrieved from https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-broadband-america-2015#block-menu-block-4

The increased latency averages for satellite-based ISPs could be problematic for the Mezzanine system to deliver HD quality services over a VPN, which requires increased overhead for connection and encryption.

b. Packet Loss

Packet loss is the term used for percentage of data packets sent by one asset on a network but not received by the attended asset. The most common reason for increased packet loss is network congestion (FCC, 2015). There will always be packet loss within a network, and in many cases network appliances use packet loss information to determine connection rates. In most cases, minor packet loss will not affect network connectivity. However, high levels of packet loss will affect perceived quality of applications such as video chat and video streaming, especially over TCP. For instance, CISCO performed research that showed packet loss as low as 0.04 percent can negatively impact video quality in part of the frame (CISCO, 2011). Figure 7 shows the average packet loss of multiple broadband service providers.

Figure 7. Chart Illustrating Average Packet Loss by ISP Vendor

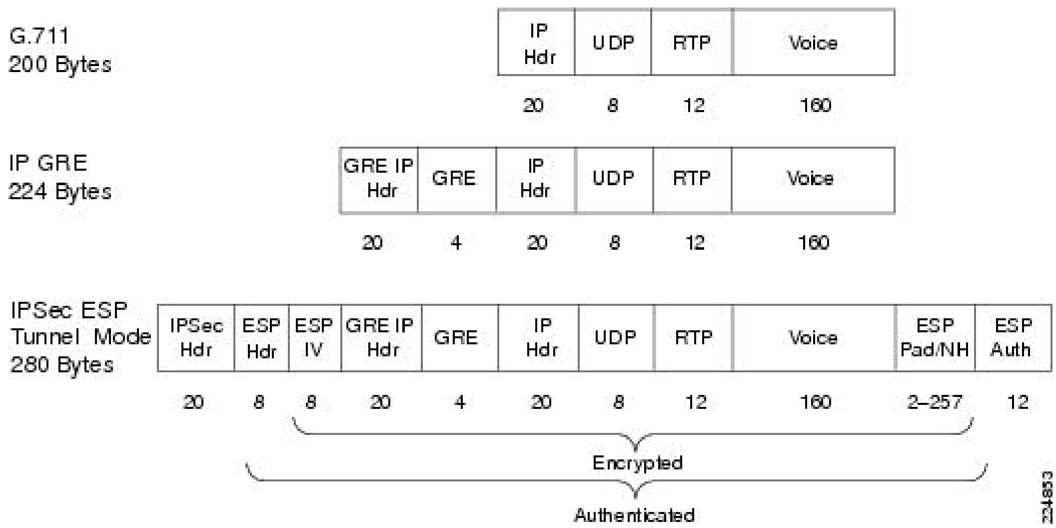


Source: Federal Communications Commission (FCC). (2015). Measuring Broadband America Fixed Broadband Report. Retrieved from: https://www.fcc.gov/reports-research/reports/measuring-broadband-america/measuring-broadband-america-2015#block-menu-block-4

3. VPN and Required Throughput Overhead

A key characteristic of working with the Mezzanine system in a Mezzanine-to-Mezzanine configuration is the requirement for the Mezzanine systems to be in an established VPN. VPN technology uses tunneling between routers to establish a logical network connection between distant sites. Generally, Internet protocol security (IPSEC) at the network layer of the open systems interconnection (OSI) model is used as a complete VPN with security solution. Using this VPN technology adds tunnel headers and encryption overhead, which increases the overall packet size of data during the processing of voice, video, and data transmissions (CISCO, 2013). This information needs to be accounted for when using limited bandwidth networks, such as satellite-based service providers. CISCO examined the use of a voice transmission using codec G.711 due to its popularity. In a standard G.711 voice call, the packet is approximately 200 bytes, the tunnel overhead adds 24 bytes per packet, and the IPSEC protocol add another additional 56 bytes, which increases the original 200 bytes to 280 bytes, adding 40 percent to the packet size. Figure 8 represents the anatomy of a G.711 packet.

Figure 8. Diagram of IPSEC Encrypted G.711 Voice Call



Source: CISCO. (2013). Enterprise QoS Solution Reference Guide. Anatomy of an IPSEC-encrypted G.711 packet. Retrieved from: http://www.cisco.com/c/en/us/td/docs/solutions/Enterprise/WAN_and_MAN/QoS_SRND/QoS-SRND-Book.pdf

D. MEZZANINE TECHNOLOGY

By leveraging the enhanced capabilities of the Oblong Mezzanine (referred to as Mezzanine hereafter), both forward operating elements and decision makers back at Headquarters (HQ) have the ability to analyze diverse data sets and operationalize multiple informational ingests geo-spatially, allowing the seamless flow of near real-time information and collaboration assessments. Imagine users being able to move a document or presentation from one screen to another when the document physically resides on a distant computer, or from a dossier within the Mezzanine. A dossier is a shared folder within the Mezzanine software that allows a Mezzanine user to share data with other Mezzanine users. This allows all users of the collaboration session to be an active participant, enabling the ability to manipulate remote objects by interacting with the local rendering of that object. The shared workspace concept allows collaborators to interact as if they were co-located. The Mezzanine architecture uses spatial computing technologies designed by Professor Hiroshi Ishii at Massachusetts Institute of Technology (MIT).

1. Spatial Computing

Spatial computing for the purpose of this thesis is defined as a human and computer interaction (HCI), where the computer or computer systems recalls and manipulates referents to objects and space based on the human's inputs to the system (Greenwold, 2003). In the past, interactions between human and computer were confined to graphical user interfaces (GUI). GUIs have been in existence since the early 1970s and commercially with the Star System since 1981. Microsoft and Apple's successes over the years with the Windows and Macintosh operating systems have set the standard of human and machine interface with the GUI. In his paper, "Tangible Bits: Beyond Pixels," MIT professor Hiroshi Ishii argues that by utilizing the GUI users cannot take full advantage of human dexterity or apply human abilities for the manipulation of physical objects such as moving papers on a display to another distant display (Ishii, 2008). Although the GUI was a dramatic technological improvement over the command user interface (CUI), it inhibits active participation during distributed collaboration sessions. According to Ishii, founder of the MIT Tangible Media Group, collaboration within the HCI is the logical next step. Ishii explains that the tangible user interface (TUI) allows digital information to be directly available through spatially aware input devices such as the Oblong Industries wand for the Mezzanine. TUI technology allows direct manipulation and capture of on-screen content during a collaboration session providing a unifying experience for the users. Additionally, Ishii notes that space-multiplexed input is another distinct feature of a TUI and provides the mechanism to synchronize objects locally or over the Internet in a dual mezzanine experience. This allows the object being manipulated in one location to be synchronized with the same object at a different location via the Internet updating the information or movement at both locations in near real-time.

Ishii was a significant contributor in the technology behind the movie *Minority Report*, where Tom Cruise's character controlled a computer system with three-dimensional gestures with his hands. Ishii also contributed to Oblong Industries' development of their gesture-controlled user environment named g-speak (Chandler, 2009). John Underkoffler, CEO of Oblong Industries demonstrated g-speak technology during a technology, entertainment, and design (TED) event. TED is a global set of conferences created by the private non-profit Sapling Foundation designed to bring ideas worth sharing to large audiences through speeches. During the TED talk, Underkoffler demonstrated the g-speak technology portrayed in the *Minority Report* movie and more recently, in the *Iron Man* movie series. Underkoffler demonstrated how advanced technologies can bridge the gap between human and computers resulting in easier and faster manipulation of data across the Internet. Spatial technology allows users to manage large amounts of data in virtual workspaces, video sessions, and large displays using natural point and drag gestures across physical and virtual environments (Oblong Industries, 2014a). Furthermore, this technology can build a single user defined operating picture (UDOP) by aggregating multiple sources of information from multiple devices into one seamless collaboration session. Figure 9 is a photograph of Underkoffler explaining the g-speak technology during a TED talk.

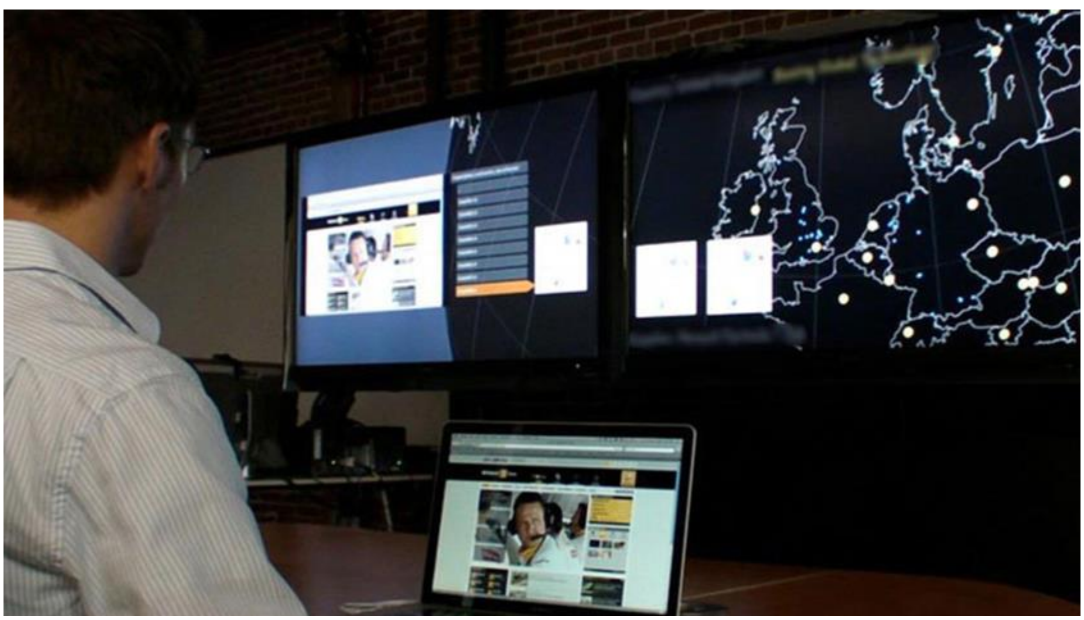
Figure 9. Oblong Industries CEO Demonstrates G-speak Technology during a TED Talk

Source: TED. John Underkoffler demonstrating g-speak technology at a TED talk. Retrieved from https://www.ted.com/speakers/john_underkoffler

2. G-speak Technology

The core technology behind the Mezzanine is g-speak, a graphical Linux and Macintosh operating system 10 (OS X) based application software package. The application is based on a multi-device, multi-user, and spatial input/output device (I/O) concept allowing for the support of any input device from a mouse and keyboard to spatially-aware gestural devices (Oblong Industries, 2015). Additionally, the software development kit (SDK) supports any number of output devices from two-dimensional (2D) projectors to three-dimensional (3D) displays. The g-speak technology allows virtually anyone using any device whether in the field or in a robust command center the ability to connect and share information. Figure 10 illustrates a user at Oblong Industries displaying images from a laptop to a large screen display.

Figure 10. Photograph Showing an Oblong Technician Demonstrating the Geometry Engine Technology



Source: Oblong Industries. (2015). Oblong G-Speak monitoring. Retrieved from http://www.oblong.com/assets/images/Oblong-g-speak-Monitoring.jpg

The g-speak technology and its ability to share data feeds including presentations and streaming video is built on two additional technologies; the Plasma networking and application framework and the Geometry engine, which are both core utilities, allowing the system to render pixels across multiple screens with real-world spatial registration (Oblong Industries, 2015).

a. Plasma

Plasma is a networking framework that allows users to interact with application video and streaming video. Plasma allows users the ability to move video between the associated devices and displays using a standard application program interface (API) (Oblong Industries, 2015). Additionally, Plasma is the framework that allows the incorporation of legacy applications into the g-speak environment, regardless of the underlying technology or operating system (Oblong Industries, 2015).

b. Geometry Engine

A pixel manipulation architecture allows the possibility of all users to move 2D and 3D data around the collaboration session to any number of screens locally or across the Internet to other displays associated with a distant Mezzanine (Oblong Industries, 2015). The Geometry Engine permits real-time manipulation and sharing of data while removing the need to send copies of data to all collaboration sites.

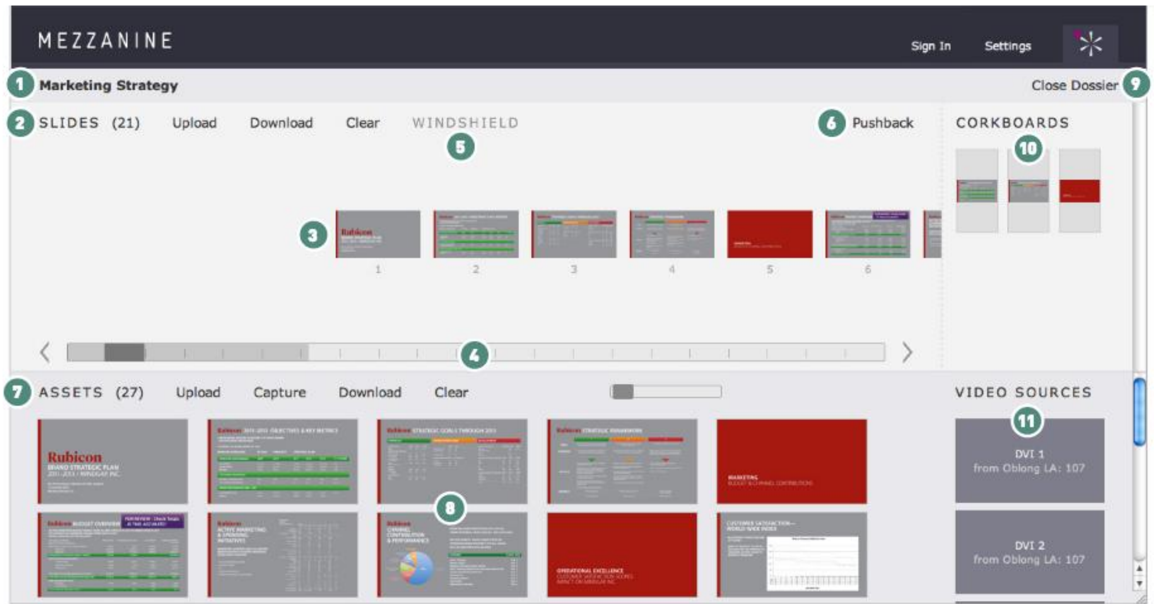
c. MzReach

MzReach is a lightweight software application designed by Oblong Industries to allow remote computers or other devices to connect to a Mezzanine. Once downloaded to the hardware device the software application allows seamless integration into a Mezzanine collaboration session.

d. Dossier

Dossiers are folders within the Mezzanine system that works much like a shared folder within a regular computer file system. The dossier provides a logical shared folder where static images, briefs, and live video streams are collected, viewed, or shared during collaboration sessions. Additionally, the Mezzanine appliance allows permission controls to secure the information as required. Figure 11 shows an example of a dossier.

Figure 11. A Dossier within a Collaboration Session Named Marketing Strategy



Source: Oblong Industries. (2014). Web application quick start guide version 2.0. Retrieved from http://www.oblong.com/assets/resources /Oblong-Mezzanine-2.0-Web-Application-Quick-Start-Guide.pdf

E. MEZZANINE CONFIGURATIONS

Oblong Industries originally designed the Mezzanine to work either as a standalone system or in a multiple Mezzanine configuration. In each configuration, the Mezzanine provides visual interactive collaboration capability. Additionally, at the request of the Naval Postgraduate School (NPS), Oblong Industries constructed an expeditionary variant and provided the system to NPS for further testing and evaluation.

1. Standalone Mezzanine Configuration

In a single Mezzanine configuration, one organization acts as the central hub of the collaboration session, maintains the central data repository, and manages the dossier. The central hub would establishes the session by having all local participants connect their devices via DVI ports or WI-FI, off-site participants connect through the Internet using the MzReach web application, and other ingests are established through streaming video or hypertext transfer protocols (HTTP).

To prepare for the session, a Mezzanine administrator creates an active conference room, allowing all session users to share information, data, and applications interactively with all participants (Oblong Industries, 2014a). This provides a unique collaboration environment, bringing personalization and group thought back into the process.

2. Multiple Mezzanine Configuration

The Mezzanine system operates with a maximum of three additional Mezzanine systems for a total of four systems simultaneously processing data and visualization. The g-speak application and Plasma framework allows all four Mezzanine systems to share the same data and video, which includes sharing the visual, displays corkboards, and VTC feeds. Any user within the session has the ability to manipulate the shared data in the dossier at the same time during a collaboration session (Oblong Industries, 2014a). Additionally, the connected systems can share up to 16 different video streams simultaneously (Oblong Industries, 2014a). Using the system in this configuration greatly enhances the capabilities and available data ingests.

In a Mezzanine-to-Mezzanine configuration, organizations have the same capabilities of a single Mezzanine configuration with the added feature of what Oblong Industries describes as InfoPresence. InfoPresence is the term describing teleconferencing with the added features of all participants able to actively share and manipulate content at the same time (Oblong Industries, 2014a). Each Mezzanine collaboration session allows for four Mezzanines connected with upwards to 48 unique contributors actively sharing information. Each contributor has the ability to interact with the shared content with locally connected devices or via the Internet using MzReach. (Oblong Industries, 2014a).

3. Expeditionary Variant

Oblong Industries designed and built an expeditionary version of their standard Mezzanine system for Naval Postgraduate School (NPS) in order to test the possibility of the Mezzanine providing advanced collaboration capability to forward operating personnel working in austere environments. The system is almost identical to a standard Mezzanine with differences to support mobility and working in austere environments. The expeditionary Mezzanine is installed in ruggedized transport cases known as flyaway kits (FLAK). The expeditionary system includes the Mezzanine components and five displays. There are two key differences. First, the ultrasonic tracking system is affixed to the top of the displays vice being installed to the ceiling and second, the displays are not hard mounted to a wall, but instead are mounted to hardware extending from the ruggedized cases. Figure 12 shows the screens attached to the ruggedized cases.

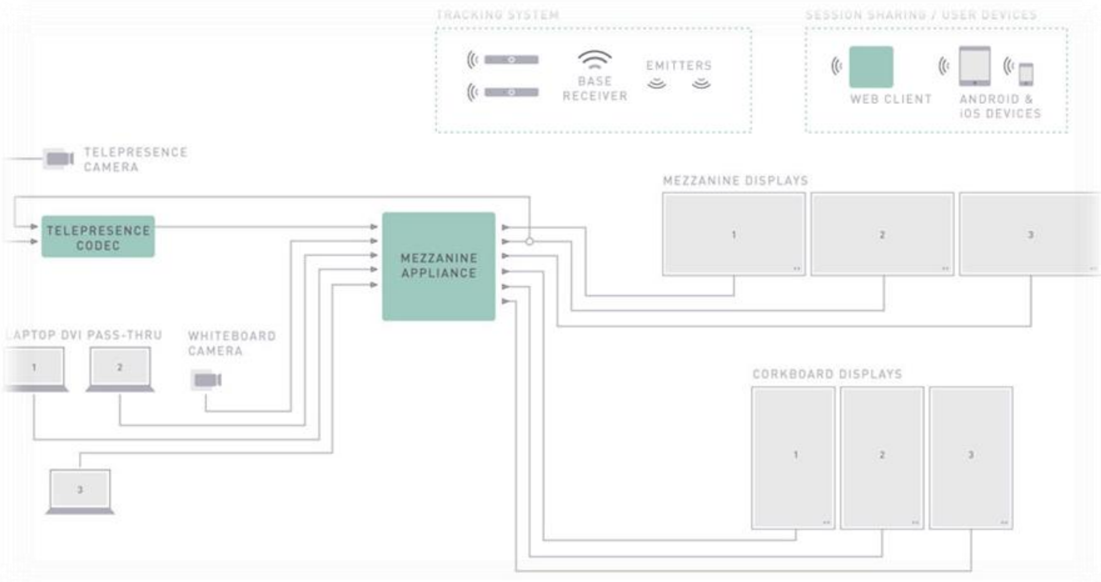
Figure 12. Photograph Illustrating Screen Placement on Expeditionary Variant Mezzanine System

F. MEZZANINE SPECIFICATIONS

The intention of the Mezzanine is to bring the user back into the collaboration environment vice using static one-way presentations. The Mezzanine deploys g-speak technology to integrate multiple digital inputs into one seamless, ubiquitous architecture, which enables collaboration between multiple geographically separated groups. The system is designed to provide multiple users the ability to manipulate data from various sources (data streams, workstations, files, etc.) on common displays. Figure 13 provides a logical diagram of the Mezzanine system. Although a Mezzanine system can be configured to support any number of configurations to suit many working environments, a typical Mezzanine installation comprises the following components:

- Mezzanine appliance (capable of driving up to 6 displays)
- Whiteboard camera
- Tracking system for spatial sensing
- Peripherals (laptops, tablets, etc.)
- Devices connected via MzReach (Oblong Industries, 2015)

Figure 13. Oblong Mezzanine Logical Diagram



Source: Oblong Industries. (2015). Mezzanine logical diagram. Retrieved from http://www.oblong.com/mezzanine/techspecs/

For this thesis, the technical specifications are subdivided into the two system variants, the standard fixed installation, and the expeditionary variant. The two systems are almost identical. However, the expeditionary variant has a few differences required to ensure the system is mobile and easy to setup in austere environments.

1. Standard Fixed System

Oblong Industries provide the following technical specifications for the standard fixed Mezzanine installation. The specification and requirements are broken down in general specifications, conference room requirements, connectivity, video and audio, networking, and security. The overall technical specifications are provided in Table 2.

Table 2. Oblong Mezzanine Technical Specifications

COMPONENT	DESCRIPTION
Mezzanine Appliance	Rack mountable tower workstation
Video Inputs	4 x DVI (or digital video equivalent) Supported Formats: 720p50, 720p59.94, 720p60, 1080p23.98, 1080p24, 1080p25, 1080p29.97, 1080p30, 1080i50, 1080i59.94, and 1080i60
Video Outputs	6 x DVI (or digital video equivalent) Supported Format: 1080p60
Network Interface Connections	1 x Network Port 1 x IP Whiteboard Camera
Tracking Interface Connections	1 x Ultrasonic Emitter Port 1 x Radio Receiver Port
Hard Drives	4 x 1 Terabyte drives RAID 10 configuration for redundancy
Operating System	Ubuntu 12.04 LTS
Dimension	4U rack-mountable appliance: 16.30 x 6.79 x 18.54 in (W x H x D)
Weight	29.1 lbs
Power	V: 100-240 V A: 6 A Hz: 47-63 Hz W: 825 W
Operating Environment	50°F - 95°F (10°C -35°C)

Source: Oblong Industries. (2014). Mezzanine Technical Overview whitepaper. Retrieved from http://www.oblong.com/mezzanine/techspecs/

a. Conference Room Requirements

Oblong Industries provides standard room requirements for the installation of a fixed Mezzanine system. The basic requirements are minimum standards to maximize the user experience and ensure the system is adequately housed.

(1) Location

The location should be a secure room that prohibits radio frequency use to ensure no interference with the ultrasonic spatial tracking system.

(2) Room Size

Typical room size 15x30 feet. Ceiling height: 9–13 feet. Maximum tracked area: 25x25 feet.

(3) Appliance Location

Per the Oblong technical specification guide, the appliance should be installed in a server room with a requirement of 12U rack space for proper cable routing and acceptable cooling requirements.

(4) Power

The appliance requires the existence of two 20amp circuits with a national electrical manufacturer association (NEMA) 5–20R socket or C-19 receptacle and one in the server room and one in the conference room.

(5) Heating Ventilation and Air Conditioning (HVAC)

The Mezzanine appliance in server room and the equipment in the conference both generate 6,000 British thermal units (BTU) of heat

(6) Lighting

Indirect lighting around the conference room perimeter and additional lighting directed at corkboard displays is recommended. Proper indirect lighting will optimize the

HD display experience and greatly reduce any glare on the corkboard displays resulting in realistic live collaboration sessions.

(7) Uninterruptible Power Supply (UPS)

Oblong Industries recommends the use of a UPS to provide time to properly shutdown system in case of a of power loss. A non-graceful shutdown could cause permanent damage to the system. The system does not ship with any UPS support. Table 3 provides recommended UPS specifications.

Table 3. Recommended Minimum UPS Characteristics

Component	Required Characteristics
Capacity	1000 Watts / 1440 VA
Max configurable power	1000 Watts / 1440 VA
Nominal output Voltage	120V or 230V
Output Frequency	50 / 60 Hertz (Hz)
Nominal input voltage	120V or 230V
Input Frequency	50 / 60 Hz

Source: Oblong Industries. (2014). Mezzanine Technical Overview. Retrieved from http://www.oblong.com/mezzanine/techspecs/

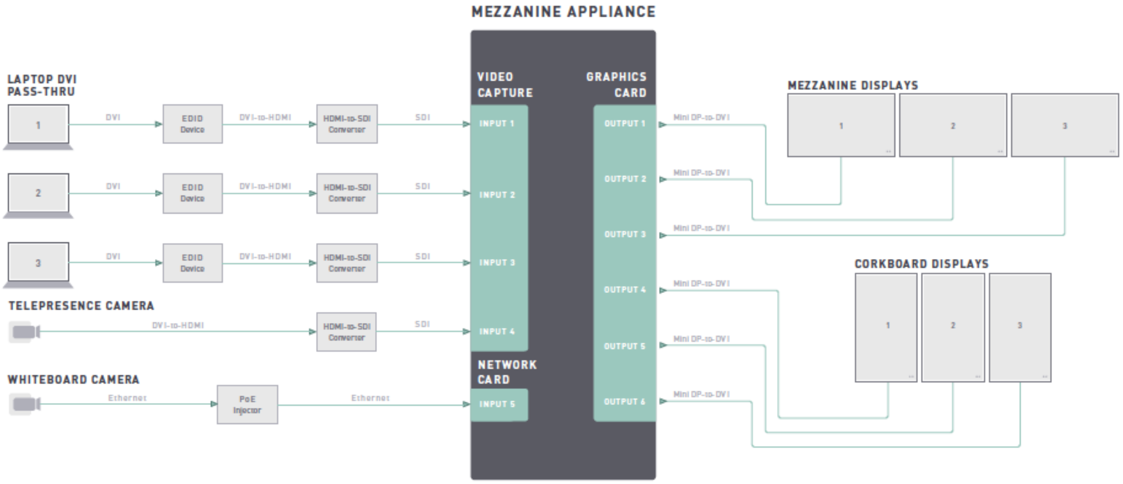
b. Connectivity (Non-Networking)

The Mezzanine system has several key components to support connectivity and manipulation, which include video, and an ultrasonic tracking system. Although the system does not come with any native audio support, Oblong can provide an auxiliary audio solution (Oblong Industries, 2014b).

(1) Video

The Mezzanine supports up to five video inputs, four of which can be high definition (HD) and one Internet protocol (IP) video stream from an IP video camera (Oblong Industries, 2014b). Figure 14 illustrates a sample video flow.

Figure 14. Mezzanine Video Flow Diagram

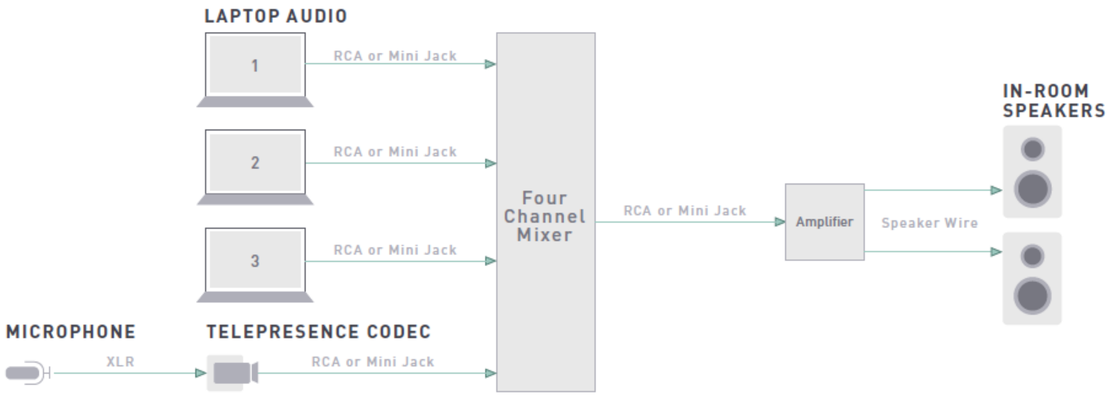


Source: Oblong Industries. (2014). Mezzanine Technical Overview. Retrieved from http://www.oblong.com/mezzanine/techspecs/

(2) Audio

Oblong Industries did not configure a native audio component to the Mezzanine system. They do provide an auxiliary audio solution as an add-on feature. Figure 15 provides a sample audio flow diagram.

Figure 15. Mezzanine Audio Flow Diagram

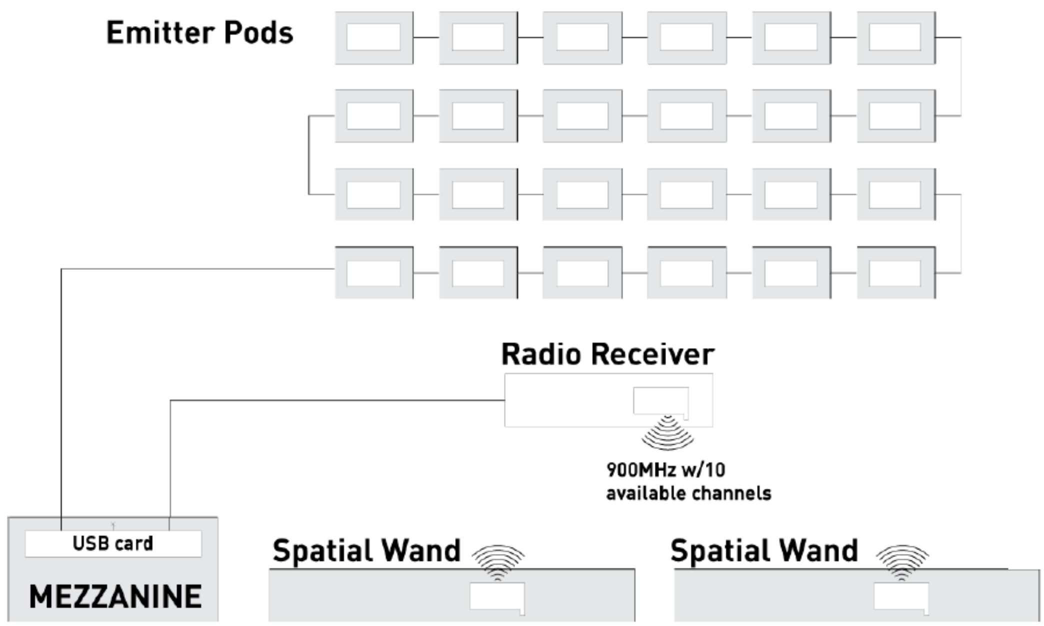


Source: Oblong Industries. (2014). Mezzanine Technical Overview. Retrieved from http://www.oblong.com/mezzanine/techspecs/

(3) Ultrasonic Spatial Tracking System

To support the spatial technology and the use of the spatial wands, an ultrasonic tracking system comes with the system. The tracking system comes standard with four primary components: two spatial wands, ultrasonic emitters, a radio receiver, and an interface card (Oblong Industries, 2014b). The system can have up to 72 emitters placed in the ceiling in numerous configurations best suited for each installation. Figure 16 shows a logical representation of the ultrasonic tracking system.

Figure 16. Typical Ultrasonic Emitter Configuration



Source: Oblong Industries. (2014). Mezzanine Technical Overview. Retrieved from http://www.oblong.com/mezzanine/techspecs/

c. Networking

The Mezzanine requires some network configurations prior to becoming operational. Each Mezzanine requires a static Internet protocol (IP) address and a corresponding domain name server (DNS) entry. According to Oblong Industries, the Mezzanine protocols are not network address translation (NAT) aware, and require to be placed on routable subnets. Using a site-to-site VPN solution is the recommended approach (Oblong Industries, 2014b). If an organization is using a wide area network (WAN) by either a VPN or virtual local area network (VLAN), the systems can be placed into a single subnet or VLAN (Oblong Industries, 2014b). For optimal performance, Oblong Industries created a draft service level agreement (SLA) stating recommended network requirements. Table 4 lists the parameters stated in the SLA.

Table 4. Mezzanine Network Service Level Requirements

Bandwidth	15 Mbps (upload and download)
Latency	< 150ms one way or 300ms round trip
Jitter	< 10ms
Packet Loss	< 0.05%

Source: Oblong Industries. (2014). Mezzanine Technical Overview. Retrieved from http://www.oblong.com/mezzanine/techspecs/

2. Expeditionary Variant

The expeditionary variant of the Mezzanine is almost identical to a standard Mezzanine system, with subtle differences to ensure its mobility and use in austere environments. Characteristics should be assumed the same as a standard Mezzanine unless otherwise mentioned in the follow descriptions. The expeditionary Mezzanine was designed to be mobile, easily setup, and preconfigured for expedient delivery of services. Figure 17 provides a visual representation of the expeditionary Mezzanine system.

Figure 17. Photograph of the Expeditionary Mezzanine System Housed in the Ruggedized Chassis

a. Overall Specifications

The overall specifications of expeditionary variant are the same as the standard fixed variant with the following differences:

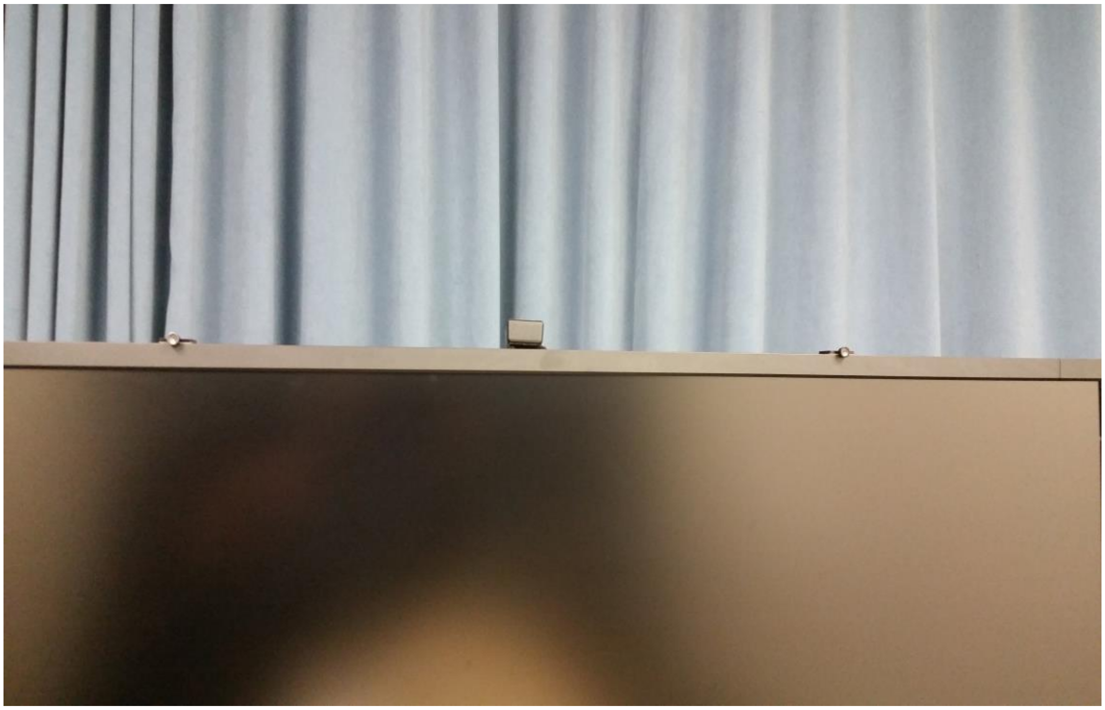
(1) Hard Drives

The expeditionary variant comes with four SATA 1Tb removable hard drives to support security and classification requirements. Therefore, the Mezzanine is pre designed to support collaboration at different levels of classification, depending on the mission.

(2) Ultrasonic Spatial Tracking System

The emitters associated with the expeditionary unit are smaller and connect to the top of the display units. Figure 18 illustrates the tracking system emitters used with the expeditionary variant.

Figure 18. Ultrasonic Spatial Tracking System for Expeditionary Mezzanine



b. Conference Room Requirements

There are no standard conference room requirements for the expeditionary variant. However, due to the footprint of the equipment and a table that will seat approximately eight people the recommendations is to have at least a 300-square-foot shelter. The shelter will require power, lighting, and HVAC support. NPS does not currently have a shelter for the expeditionary Mezzanine. The researchers found a few suitable shelters that could be used to support this requirement. The Drash unit weighs approximately 624 lbs. and has 442 sq. ft. of usable space. Drash documentation states two people can assemble the M-series shelter in less than 15 minutes (Drash, 2015). Figure 19 is a picture of an M-series Drash shelter.

Figure 19. Example of Expeditionary Tent with Power and HVAC Support

Source: Drash. (2015). M series shelter. Retrieved from: http://www.drash.com/Products/Shelters/MSeries.aspx

(1) Power

The expeditionary Mezzanine located at NPS can run on organic power or the gas powered Honda 2000i generator associated with the EOC in a Box. A tactical power unit is used for UPS coverage when organic power is not available.

(2) Lighting

The Mezzanine system should be enclosed in a room or tent that provides sufficient indirect lighting for the sensors to work properly and to ensure the displays are viewable.

(3) HVAC

General Service Administration (GSA) standards for communication equipment within the government are 74 degrees in summer and 72 degrees in winter (General Service Administration, 2014). The shelter and associated cooling equipment should be rated to keep the operating temperature between 74 and 80 degrees.

G. HASTILY FORMED NETWORKS

Generally, an HFN can be defined as a rapidly deployable communication system providing organizations, usually first responders or expeditionary forces, a command and control infrastructure. The first priority in any event, especially a catastrophic event is to setup a means to communicate. According to Denning (2006), first responders require an efficient C2 capability in order to establish situational awareness. Denning continues to emphasize that there are five key components of an HFN.

> An HFN has five elements: it is (1) a network of people established rapidly (2) from different communities, (3) working together in a shared conversation space (4) in which they plan, commit to, and execute actions, to (5) fulfill a large, urgent mission. (Denning, 2006)

The concept of establishing the shared conversation space is what enables an HFN to efficiently provide C2, and allow a means for multi-agency response and CMMs to establish organized command structure. The conversation space is further defined by Denning (2006) as having three main components: (1) A communication medium, (2) players, and (3) an agreed upon set of rules. The EOC in a Box coupled with a Mezzanine can quickly create a mechanism for establishing interoperability, information sharing, and help to establish trust among agencies. Furthermore, this configuration has the potential to meet Denning's requirements of a successful HFN infrastructure by enabling the five elements of an HFN and the three components of the conversation space. In numerous occasions, such as in response to Hurricane Katrina or the 2010 Haiti earthquake, the EOC in a Box has proven to be a viable means of providing C2 to first responders.

1. Emergency Operations Center in a Box (EOC in a Box)

The EOC in a Box is a system that provides organizations with a robust, mobile communication suite utilizing HFN concepts and virtual machine (VM) technology. The network consists of COTS equipment supporting both wireless and hardwired network routers and switches. In designing the system, the key components were power, mobility, and communication capability (Baretto, 2011). The EOC in a Box enables two cloud-computing services: SaaS and IaaS in a private or public cloud model.

a. Virtual Machine Technology

Virtualization technology has grown in importance over the years and system developers use virtualization as a tool when designing computer systems to overcome using specific instruction set architecture (ISA). ISA is a well-defined interface code designed to set specific specifications in the computing platforms, so software developers can create applications that will work with the system(s) correctly (Smith & Nair, 2005). The use of ISA architecture design creates hierarchies with separate levels of abstraction, so these varying levels of well-defined interfaces reduces system complexities at the hardware and software level of the code, resulting in reduced complications when designing software and applications to work on the platform (Smith & Nair, 2005). However, well-defined hierarchical systems such as the Intel-32 (x86) instruction has limitations with interoperability. VM technology uses software called a virtual machine monitor (VMM), such as a hypervisor to support desired architectures, thus eliminating the real machine compatibility and hardware resource constraints (Smith & Nair, 2005). The use of virtual technology allows increased interoperability with users requiring varying hardware and software requirements, resulting in more effective collaboration sessions. The EOC in a Box supports the following technologies:

- Server: The most common type of virtualization due to the cost savings it provides. Server virtualization removes the need to have a physical server; instead, there is a virtual image of the server running on the virtual drive stack. This reduces the need for hardware associated with one service, energy savings, and easier disaster recovery processes.

- Storage: A concept referring to the abstraction of logical storage containers from physical storage devices, resulting in increased flexibility for storing data.
- Desktop: The process of using a virtual desktop infrastructure (VDI) to separate the user desktop environment from a physical workstation. By using this process, the EOC in a Box can host multiple OS with the VM infrastructure on a centralized server. This provides both flexibility and interoperability with multiple users with varying requirements.

The VM technology running on the EOC in a Box allows the system to provide a cloud-computing infrastructure supporting both IaaS and SaaS computer services in austere environments.

b. Infrastructure as a Service

NIST defines IaaS as the cloud computer service model that provides operators the ability to request computer processing, storage, network access, and computer resources from the operating system (Mell & Grance, 2009). The EOC in a Box was designed using VM architecture to provide IaaS in a lightweight highly deployable configuration that can provide C2 and interoperability with any network and legacy systems.

c. Software as a Service

NIST defines SaaS as the model that provides users the ability to access and run applications residing on the provider's infrastructure using thin client interfaces such as web browsers (Mell & Grance, 2009). EOC in a Box provides SaaS connecting users to web-based email, MZReach, and other applications as needed.

2. EOC in a Box (as tested)

The EOC in a Box, as tested contained eight COTS components configured for adaptability and interoperability:

- **Virtualization Server:** The EOC in a Box utilizes V3 systems VDI server integrated into a VMware ESXi environment. This configuration provides users with active directory (AD), DNS, and other supporting services.

- **Storage:** The system is configured with a storage attached network (SAN) connected via advanced technology attachment (ATA) over the Ethernet protocol, providing scalable storage up to 12TB.

- **Switching:** A power over Ethernet (POE) CISCO 2000 24-port switch is used to provide internal communication between equipment.

- **Wireless Networking**: A Cradle point MBR 1400 wireless network router is used as an access point for internal systems. This configuration allows the internal network configuration to remain static.

- **Uninterruptable Power Supply (UPS)**: A ruggedized tactical power system is used to provide power conditioning and backup power.

- **Power Distribution Unit (PDU):** Providing 120volt outlets for associated equipment

- **Ruggedized Chassis:** All equipment is installed in a ruggedized portable chassis (Barreto, 2011, pp. 45-53).

The EOC in the Box as tested weighs approximately 197 lbs. allowing for two-man lift capability. Figure 20 illustrates the system configuration in the ruggedized chassis. Figure 21 illustrates the ruggedized chassis closed ready for shipment.

Figure 20. Photograph of EOC in a Box System within the Ruggedized Case

Figure 21. Photograph Showing the EOC in a Box Prepped for Shipment

The EOC in a Box was designed to be mobile and support working in austere environments. Many times when working in austere environments or in areas after a natural disaster electrical power and fuel may not be readily available, and systems supporting personnel in these environments need to operate efficiently to preserve power and fuel.

a. Communication Connectivity

The EOC in a Box can connect to any land-based or satellite-based network infrastructure via a category six cable (CAT 6). During testing, the EOC in a Box was connected to a ViaSat Surfbeam 2 Pro portable satellite terminal (SB2). The SB2 system is designed to be a lightweight, deployable communication system that can provide high-speed Internet connectivity in austere environments (ViaSat, 2013). This capability facilitates on the move (OTM) communication networks providing a quick and efficient C2 operating environment. The terminal provides high-speed Internet access, supporting file transfer, cloud-computing applications, VPN connectivity, and video streaming (ViaSat, 2013). Additionally, the advertised throughput is up to 40 megabits per second (Mbps) downstream and 20Mbps upstream. In theory, this throughput is sufficient for almost any C2 requirement for small operating units. ViaSat (2013) further advertises the embedded software allows operators to configure segregated classes allowing each class to be set for differing throughput based on need (ViaSat, 2013). This feature provides a dynamic environment allowing a configurable C2 infrastructure and efficiently using available throughput based on unit needs vice having a single network competing for bandwidth. Figure 22 is a picture showing the SB2 system fully assembled, disassembled and stored in the associated ruggedized case.

Figure 22. Image of the ViaSat Surfbeam 2 Pro Portable Terminal Setup and Disassembled in Ruggedized Case

Source: SATCOM Resources. (2015). ViaSat Surfbeam 2 Pro portable terminal. Retrieved from http://www.satcomresources.com/Viasat-Exede-Pro-Portable-Satellite-Terminal

The SB2 system was designed for operations in harsh environments and meets military standard specifications (MIL-STD-810), and can provide connectivity for the EOC in a Box and Mezzanine in virtually any location. The system supports both AC and DC power, and can be disassembled and placed into a ruggedized case that meets commercial airline baggage requirements weighing 55lbs (ViaSat, 2013).

b. Power and Fuel Consumption

When the EOC in a Box is not connected directly to a power source, the system uses a portable power generator. Currently the Honda EU2000i portable generator is used with the system. This generator is quiet, portable, and lightweight, weighing less than 46lbs. The Honda EU2000i generator uses a Honda exclusive Eco-Throttle system providing clean and fuel efficient power, running 3.4 to 8.1 hours on a single tank of fuel (Honda power equipment, 2015). Table 5 shows the rated specifications of the Honda EU2000i generator.

Table 5. Honda EU2000i Generator Specifications

Engine	Honda GX100
Displacement	98.4cc
AC Output	120v 2000W max (16.7A) 1600W rated (13.3A)
Receptacles	20A 125V duplex
DC Output	12V, 96W (8A)
Starting System	Recoil
Fuel Tank Capacity	.95 gallon
Run Time per Tankful	3.4 hour @ rated load 8.1 hours @ ¼ load
Dry Weight	45.6lbs

Source: Honda Power Equipment. (2015). EU2000i generator. Retrieved from http://powerequipment.honda.com/generators/models/eu2000i

Barreto (2011) measured the power consumption for the EOC in a Box and determined the system used 550.04 watts per hour (W/h). Table 6 represents the power consumption of the EOC in a Box during field-testing.

Table 6. EOC in a Box Power Consumption

Equipment	QTY	Power (Watts)	Power Total (Watts)	Current (Amps)	Current Total (Amps)
V3 Strato Server	1	Left P/S 100.15 Right P/S 91.82	191.97	Left P/S 0.88 Right P/S 0.82	1.7
CISCO SGE2000P Switch	1	20.27	20.27	0.19	0.19
USB KVM	1	<1	1	<1	1
Coraid	1	336.8	336.8	2.8	2.8
Total			550.04		5.69

Source: Barreto, A. (2011). Integration of virtual machine technologies into Hastily Formed Networks in support of humanitarian relief and disaster recovery missions (Master's Thesis). Retrieved from http://Calhoun.nps.edu/public/handle/10945/10736

The generator can support the power requirements of the EOC in a Box when there is no power available, and can charge the UPS batteries to keep the system ready at all times. Comparing the results from Tables 5 and 6, the Honda EU2000i generator has sufficient capacity to power other devices while providing power to the EOC in a Box.

III. RESEARCH APPROACH

This chapter presents approaches for evaluating Mezzanine and EOC in a Box as possible contributors for advanced collaboration capabilities in support of C2 activities in an austere environment. Based on the original research questions, the researchers seek to answer the following questions:

- Does Oblong Mezzanine support C2 in an austere environment?
- What factors are crucial for deploying EOC in a Box and Mezzanine?
- What does the use of Mezzanine enable from a mission perspective?

In previous chapters, system architectures and design were discussed to ascertain that the Mezzanine meets expeditionary requirements. Three evaluations were designed to give researchers a chance to evaluate these technologies against the initial research questions. The objective was to determine if these capabilities would improve C2 capabilities in an austere environment.

In designing these evaluations, it was determined that answering the original research questions would be too difficult and beyond the scope of this thesis. Because the researchers had no access to an actual deployed unit operating in austere environment, only subjective interpretation of the efficacy of Mezzanine and its advanced collaboration capabilities could be determined. Three different evaluations were conducted.

A. PERFORMANCE BASELINE EVALUATION

To baseline the system and witness the system in operation as designed, for the first evaluation the researchers arranged an observation of the Mezzanine system at the Menlo Park offices of Oblong Industries. Oblong Industries associates conducted a Mezzanine-to-Mezzanine session to demonstrate the system's capabilities and the quality of the link while streaming HD video. The purpose of this evaluation was to conduct measurement of the bandwidth, latency, and if possible, any jitter noted during Mezzanine operations in a non-austere environment. Furthermore, as pointed out in Chapter II, it was not clear that even commercial grade Internet services are sufficient to support high definition Mezzanine activities. This evaluation also measured that performance.

1. Evaluation Set Up

The two Mezzanine systems were connected via an established VPN between the Oblong Industries' sites at Menlo Park, California and Washington, DC.

For traditional video streaming such as VTC, a symmetrical link speed of 256kb to 384kb is more than adequate to provide a quality connection. However, the actual VPN link speed required for Mezzanine-to-Mezzanine is 15Mbps (Oblong Industries, 2014b). One assumption that we make is the VPN link in a traditional Mezzanine-to-Mezzanine sessions will normally be much higher than 15Mbps in both directions, but not necessarily be symmetrical.

a. Measurements

The measurements for the baseline observation will be compared to the FCC findings in its report on broadband ISP service providers and three separate demonstrations witnessed by NPS faculty and student researchers. Referencing the FCC report in Chapter II, the researchers assume Oblong Industries use a well-known land-based ISP that provides sustained speeds allowing HD quality streaming video.

b. Objective

In this first evaluation, the researcher planned to query the Oblong team on bandwidth, latency, and jitter measures. Furthermore, the team would use the evaluation as a chance to learn more about the nuances of VPNs as they applied to Mezzanine operation. As noted in Chapter II, VPN can add significant overhead to TCP/IP operations. This constant size overhead is generally insignificant in a 15Mbps environment, but may provide an increasing constraint in austere environments.

c. Qualitative

The researcher also planned to conduct subjective evaluation of the video and imager quality on the various Mezzanine displays. The intent was to consider how much degradation could be experienced and still enable Mezzanine to be useful.

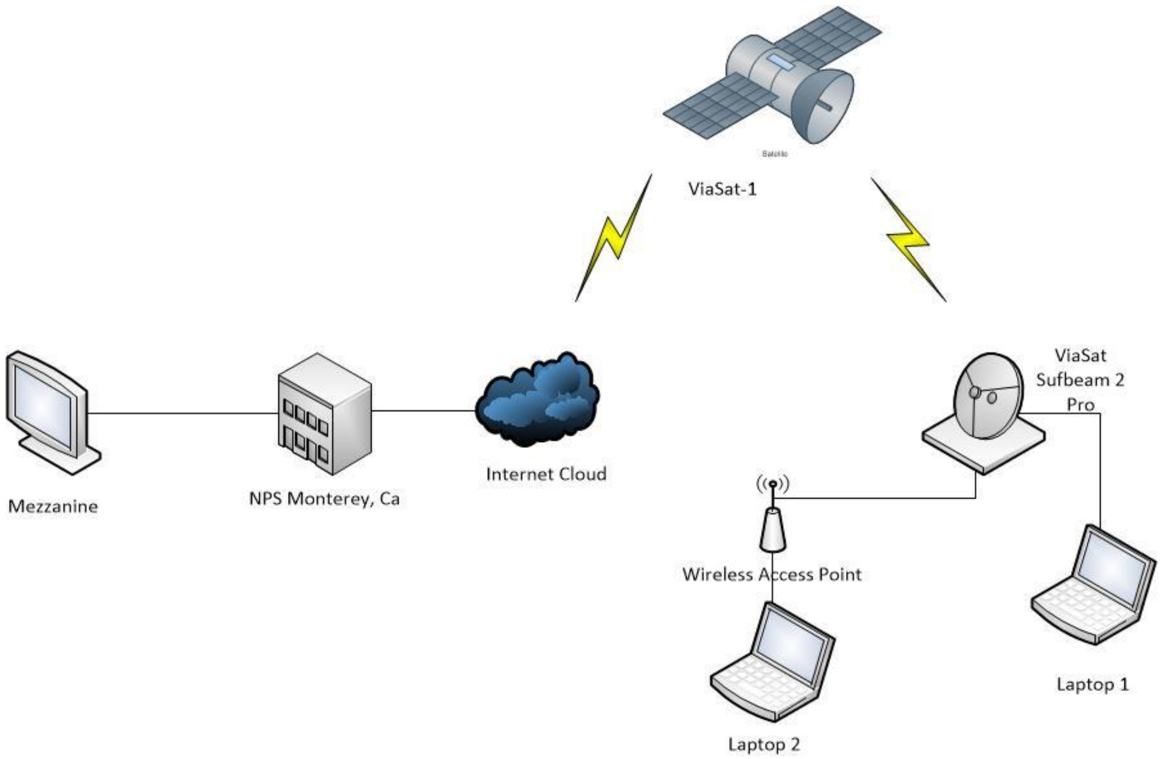
B. EVALUATION TWO

The second evaluation took place at NPS, where the EOC in a Box, Expeditionary Mezzanine, and the satellite equipment are located. This evaluation was designed to measure the performance of the Mezzanine by interacting with the system via the EOC in a Box connected to a satellite-based ISP, replicating an austere environment. Much like the baseline evaluation, the purpose of this evaluation was to conduct measurements of bandwidth, latency, and jitter noted during Mezzanine operations in an austere environment. Additionally, as discussed in Chapter II, the use of satellite-based ISPs are both limited by TCP/IP protocols designed for land-based connected networks, and have increased propagation delay due to distance from the ground-based modem to the satellite. The hypothesis is that this characteristic of satellite network communication would have a negative impact on the use of a system requiring high bandwidth such as the Mezzanine.

1. Evaluation Set Up

The evaluation was setup based on a similar study conducted at the University of Palermo to evaluate TCP performance over satellite channels. Figure 23 is an image illustrating the configuration for evaluation two. The Mezzanine was setup as part of the NPS network to simulate the system in use at a military headquarters. The EOC in a Box was setup in the NPS courtyard to simulate working in an austere environment. The researchers will evaluate the performance of the satellite connection from two sources. The first source will be a laptop directly connected to the SB2 modem, the second will be a laptop connected via a wireless access point associated with the EOC in a Box system. As previously discussed in Chapter II, this evaluation will help determine how the Mezzanine will work over a satellite-based ISP with increased latency, and potential bottlenecks associated with the satellite paradigm.

Figure 23. Logical Description of Evaluation Connections



Adapted from Neglia, G, Mancuso, V., Saita, F., and Tinnirello, I. (n.d.). A simulation study of TCP performance over satellite channels. Retrieved from: http://www-sop.inria.fr/members/Vincenzo.Mancuso/NMS02.pdf

2. Measurements

The measurements during evaluation two will be conducted by using the Ping for Life utility over the Internet control message protocol (ICMP) to determine network performance by monitoring trip times for packets traveling over the satellite link. These will be based on established measurements in the field.

a. Objectivity

In the second evaluation, the researcher planned to monitor the bandwidth, latency, and jitter while sending test data over the satellite link to the Mezzanine system residing within the NPS network. Further, the team would use the evaluation as a chance to witness the Mezzanine system performance as a whole receiving products and streaming video in a simulated austere environment.

b. Qualitative

The research team also planned to conduct subjective evaluation of the video and image quality on the various Mezzanine displays. Again, the intent was to consider how much degradation could be experienced and still enable Mezzanine to be useful. This data would be used to compare the performance witnessed during evaluation one and determine how much a satellite link using link-asymmetry and how increased round-trip time and packet loss would affect the usefulness of the system.

C. EVALUATION THREE

The third and last evaluation was to collect power usage data and weight characteristics of the Mezzanine system. The researchers want to determine two factors, the first factor is to determine if the single Honda generator associated with the EOC in a Box can provide sufficient power to the Mezzanine system in case of no organic power is available, and second, to determine the weight of each piece of the expeditionary Mezzanine system.

When working in austere environments the availability of power becomes a critical factor. The system as a whole can employ organic power available at the site. However, in many cases working in austere environment will require the system to be powered by generators. The researchers want to determine if the current Honda generator associated with the EOC in the Box can provide power to the Mezzanine, and if not, would it be better to purchase a second generator or larger generator.

Weight also becomes a critical factor when working in an expeditionary environment. The researchers will determine the exact weight of the expeditionary Mezzanine system to provide insight into how the system can be deployed.

1. System Set Up

To determine the power consumption of the Mezzanine system researchers will evaluate the expeditionary Mezzanine as it would be setup when deployed.

2. Measurements (Power)

The onboard Sentry PDU software will be used to monitor power consumption by monitoring the amperes (Amps) being used over time. The results will then be added to the known power draw of the EOC in the Box discussed in Chapter II to determine the power requirements of both systems operating together, and whether the current generator can support both systems.

a. Objectivity

In the third evaluation, the researcher planned to monitor the ampere usage during initialization, normal usage and shutdown sequence of the system, while connected to stable power in the NPS conference room.

b. Qualitative

The research team also planned to conduct subjective evaluation of the power consumption based off the advertised capability of the Honda generator and multiple field experiments conducted with the EOC in a Box system. This data would be used to compare the advertised performance capability of the current generator providing power, two generators in tandem, and the possibility of using a larger generator with increased capability without sacrificing the expeditionary capabilities.

IV. RESULTS OF EXPERIMENTS

This chapter discusses an observation of the Mezzanine system conducted at Oblong Industries and two evaluations conducted at NPS to analyze the Mezzanine system, and its potential as a collaboration tool connecting disparate systems in austere environments. In previous chapters, system architectures and design were presented to ascertain the Mezzanine system meets expeditionary requirements. Initially, three experiments were discussed that would prove beneficial to organizations wishing to incorporate the Mezzanine into their C2 structure. However, due to fiscal constraints and satellite equipment availability only two experiments were conducted to determine power consumption and weight characteristics of the system.

A. RESULTS EVALUATION ONE

The Mezzanine is designed to work in a multiple Mezzanine configuration using land-based ISPs having virtually unlimited bandwidth available to each Mezzanine session. This first evaluation witnessed the Oblong Mezzanine functioning in this best-case scenario, and the platform functioned as designed.

Based on the 2015 report from the FCC measuring ISP speed performance, and the FCC broadband speed guide discussed in Chapter II, Oblong appeared to be using a credible land-based ISP providing continuous speeds that exceed 4Mbps, and with assumed speeds much higher. During the evaluation, the researchers witnessed no noticeable degradation sessions between the two Oblong Industry sites.

Of note, the only degradation noticed was actually with the expeditionary Mezzanine located at NPS when compared to the fixed installation at Oblong Industries. The degradation noted was with the ultrasonic spatial tracking systems and the associated hand wand. The standard Mezzanine has the sensors installed on the ceiling providing a horizontal plane, while the expeditionary Mezzanine has the sensors attached to the top of the display units providing a vertical plane. The fidelity shows a noticeable decrease with the expeditionary enabled sensor system, which reduces the performance and response time during sessions. While degraded, the system was still quite usable.

B. RESULTS EVALUATION TWO

While the Mezzanine system was initially designed to be installed in a business environment with dedicated equipment and conference room utilizing land-based ISPs with dedicated VPN connections, the expeditionary version built for NPS has to be able to work in DIL environments. To replicate an austere environment during Evaluation Two, the EOC in a Box was used to provide IP services. The EOC in a Box was setup outside in the courtyard of NPS and connected to a SB2, with power established by the Honda generator. The researchers established satellite connectivity, and conducted speed tests to determine a baseline prior to connecting to the Mezzanine system. The SB2 was connected to ViaSat 1 satellite and a signal-to-noise ratio (SNR) of 14.7 was established.

The evaluation was less than successful. Initially, the plan was to have the Mezzanine ingest feeds from two workstations connected to the EOC in a Box and determine how the Mezzanine adapted to data coming in from DIL network nodes. However, during this evaluation a connection could not be made between the Mezzanine behind the NPS network and the EOC in Box via the satellite ISP.

The researchers thought the connection issues were based on the port and protocols established by the network administrators at NPS and troubleshooting commenced with Information Technology and Communication Service Center (ITACS) network security personnel. After the correct ports and protocols were verified, connectivity to the Mezzanine still could not be established.

The research team decided to focus on the satellite connection parameters to ascertain the satellite ISP could provide the necessary throughput for the Mezzanine. The network configuration was setup in accordance with Figure 23 and two ping for life tests were conducted to establish packet travel time from the EOC in a Box network and the NPS network.

During both Ping for Life tests, the researchers noticed that there were identical packet failures. Several of these failures were noticed at the beginning of the test and then every sixth packet. For the first few failures, it was assumed the system was updating the address resolution protocol (ARP) table via the satellite-based ISP, which is normal.

During a Ping request, there would be no ARP table for the destination host and the first packet would not be sent, but an ARP request would be sent then the following packets would succeed. The phenomena of every sixth packet was interesting and additional research concluded this was also an expected characteristic.

After further research, the team determined the packet loss to be a denial of service (DoS) attack mitigation procedure using rate limiting. Rate limiting is a procedure many data providers adopt to prevent permanent DoS attacks, which places a threshold on incoming network traffic. (Rao & Rao, 2011). According to Deal, a CISCO professional, rate limiting is a configuration on the internal network to prevent the amount of outbound traffic sent to a node as a temporary safeguard against a distributed denial of service attack (DDoS) such as a Smurf attack (Deal, 2004). This directly correlates to what the researchers witnessed during each set of Ping for Life tests. Figure 24 is a chart showing the results from the first Ping for Life test conducted from the workstation directly connected to the wireless access point on the EOC in a Box network. Figure 25 is the chart showing the results from the second Ping for Life test from the workstation connected directly to the SB2 modem.

Figure 24. Chart Illustrating the Results of the First Ping for Life Test

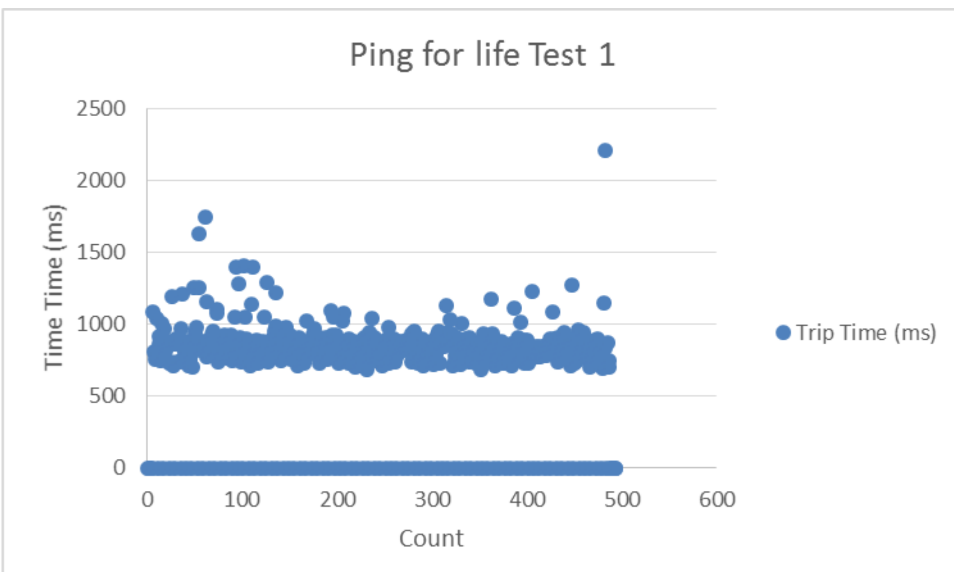
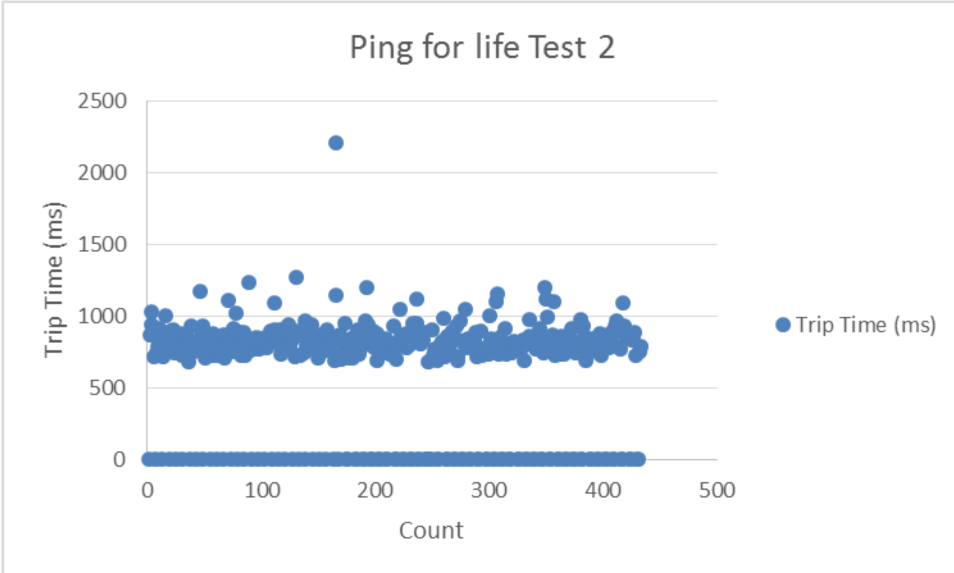


Figure 25. Chart Indicating the Results for the Second Ping for Life Test



For each test, the research team assumed any trip time higher than 1200ms was an anomaly, and packet failures during the initialization, and every sixth packet was discarded from the equation. After the new parameters were set, the researchers derived the mean, min, max, and standard deviation from the trip time set. Table 7 is a comparison of the data derived from both Ping for Life tests.

Table 7. Trip Time Calculations

	Test 1	Test 2
MEAN	841.66	832.678
MIN	684	680
MAX	1190	1196
StdDev	91.378	91.222

The results show the average trip time during evaluation two were approximately 200ms greater than the results acquired by the FCC discussed in Chapter II.

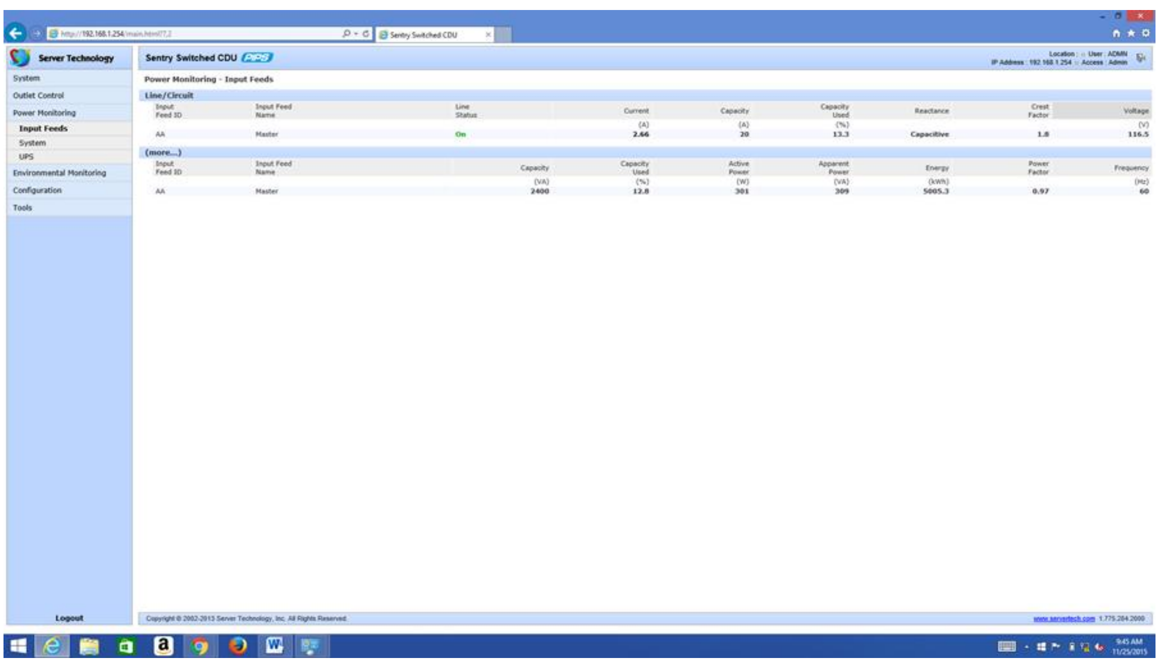
Because the connection to the Mezzanine could never be established, the researchers were unable to gather data on packet loss and jitter.

C. RESULTS EVALUATION THREE

1. Power Consumption

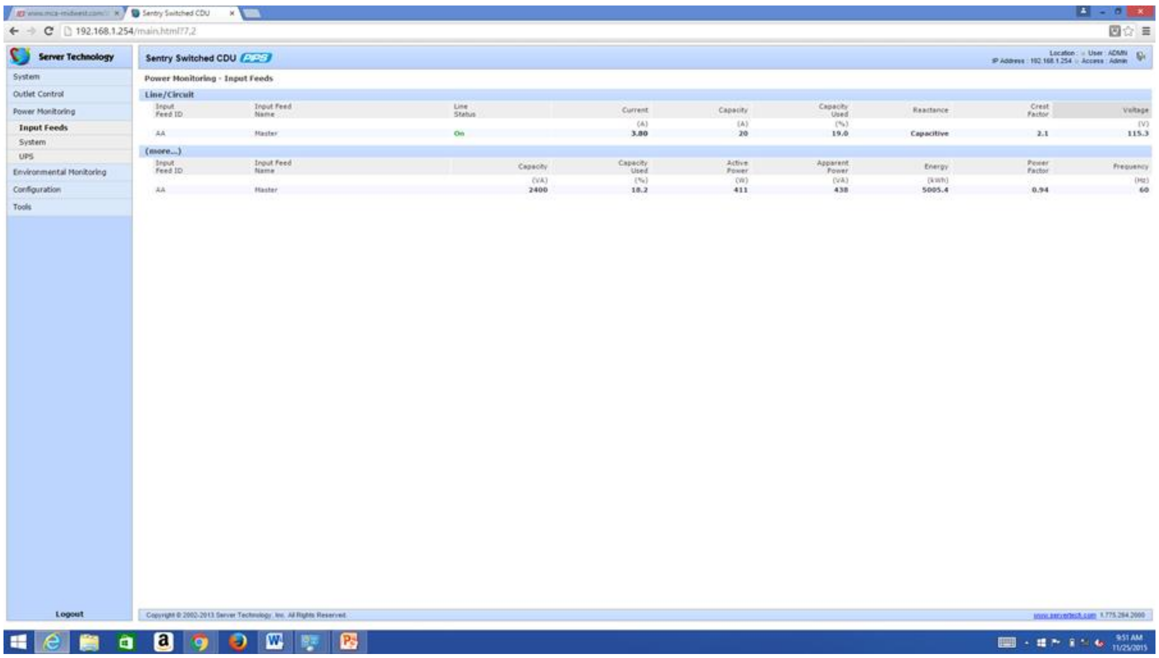
The final evaluation was to determine the power consumption and weight of the Mezzanine system. To find the power consumption the researchers ensured that device power was plugged into the Sentry PDU. However, for this test it was only feasible to connect two of the five monitors into the PDU. The team then shutdown the entire system to capture the power load during initialization. No monitors were turned on during the initialization of the system since the research team needed to determine what monitor would be used to further calculate the total for all five monitors. The system used 2.66 amps total, which was 13.3 percent usage of the PDU total capacity. Figure 26 is a screen capture of amps being used during initialization.

Figure 26. Screen Capture from the Sentry PDU Management Software Showing Current and Power Capacity Used during Startup



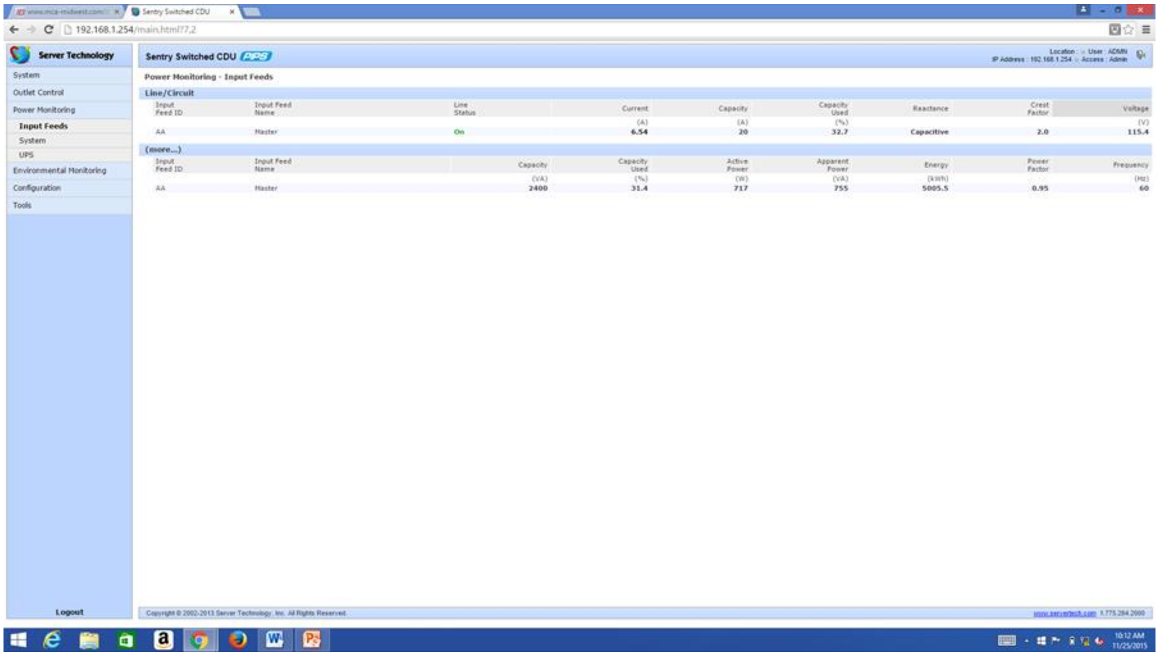
To stabilize the system’s power consumption the researchers let the system operate for 10 minutes without using the monitors. After the 10-minute mark, the Mezzanine steadied at 3.80 amps. Figure 27 is a screenshot of the Sentry PDU management software showing amps used after 10 minutes of being powered.

Figure 27. Screen Capture from the Sentry PDU Management Software Showing Current and Power Capacity after 10 Minutes of Usage



Next, the researchers determined each display increased the amps used by 1.37 amps. The system operated for 10 additional minutes with two monitors online and the total amps was noted at 6.54 amps resulting in using 32 percent of the total usage of the Sentry PDU. Figure 28 illustrates the total amps and percent of capacity of the Sentry PDU the Mezzanine systems used including two displays.

Figure 28. Screen Capture from Sentry PDU Management Software Displaying Total Amps and Percent of Capacity for Mezzanine and Two Operational Displays



At this point, the researchers assumed each additional display operates at 1.37 amps, which is in line with the manufacturer stating the NEC X55s display operates approximately at 160w. The researchers divided the 160 watts by the voltage and found amps (160w/120v=1.33amps). The manufacturer’s stated wattage and amps were to be very close to those observed in the evaluation. The research will assume each display will operate at approximately 1.37 amps, and the total power consumption with all five displays operating will be approximately 10.60 amps.

2. Weight

To consider the expeditionary Mezzanine to be mobile, the research team wanted to figure out the total weight of the system to calculate and plan for movement of the system as configured. Table 8 illustrates the weight characteristics of the Mezzanine system. The total weight of the system to include all ruggedized cases is approximately 1,605 pounds.

Table 8. Table Illustrating Size and Weight of each Appliance within the Mezzanine System

Device	Dimensions (L/W/H)	Weight per unit lbs	Qty	Total Weight lbs
Dell Deminsion R5500	3.4 x 18.9 x 27 (H/W/D) in	37	1	37
Tandberg TTC6-08	1.75 x 17.4 x 16.7 (H/W/D) in.	17.6	1	17.6
Sentry 8H1A113 PDU	1.75 x 17.2 x 7.1 in	6.2	1	6.2
Crestron HDMI/fiber	5.92 x 3.91 x 1.43 (H/W/D) in	<1	7	7
Crestron Audio extender	1.68 x 5.12 x 3.79 (H/W/D) in	<1	6	6
NEC X552S Monitor	49.2 x 28.5 x 1.8 in	55.1	6	330.6
Bose surround sound	3 x 24.75 x 14 (H/W/D) in	12	1	12
Video camera	5.4 x 4.9 x 6 (H/W/D) in	1.76	1	1.76
Monitor Case Jelco	37x 21 x 71 in	179.9	6	1,079.40
Oblong SKB Case	43.5 x 26.50 x 23.50 in	76	1	76
Peripherals case	30.75 x 20.5 x 11.62 in	41	1	32
Total weight				1605.56

Commercial airline carriers have strict baggage weight restrictions, and based on the top five U.S. airline carriers the average overweight baggage accepted is between 50 and 100 pounds (Alaska Airlines, 2016; American Airlines, 2016; Delta Airlines, 2016; Hawaiian Airlines, 2016; United Airlines, 2016). This is an important fact as the combination of each of the five displays and the ruggedized cases exceed these weight restrictions alone. The researchers will assume a freight carrier or military lift will be required to transport the Mezzanine.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This research commenced with two goals in mind centered on the expeditionary Oblong Mezzanine's ability to provide collaboration and C2 support using tactical communication systems in austere environments. The first goal was to determine how the Mezzanine works in an austere environment, and the second was to identify use cases for the Mezzanine in the future. Quantitative and qualitative metrics were developed using a thorough literature review, analysis of distributed collaboration, and lessons learned from DOD experiences operating in HADR environments. This research evaluated the Mezzanine and attempted to determine if the system could work in austere environments using bandwidth challenged communication paths.

A. CONCLUSIONS

1. How can the Oblong Mezzanine advanced collaboration system be used to provide effective C2 in austere environments?

In Chapter II, the researchers discuss how effective C2 requires collaboration, and how the Oblong Mezzanine system can provide a collaboration solution that joins people and data in an immersive cooperative environment. Assuming operators know how to use the system, the Mezzanine would enhance C2. As discussed in Chapter II, the system works at the pixel level with virtually no restrictions on hardware or software compatibility. Assuming operators were using the system in an austere environment that has access to high-speed ground-based Internet services, like those environments recently encountered in Iraq and Afghanistan, the Mezzanine as designed could be employed as an input/output device to ingest multiple data streams and output them to various displays. One Mezzanine appliance can receive ten video inputs five of which can join via network connected devices. This creates a real-time collaboration session among multiple players enabling them to quickly orient themselves and make decisions based on their current situation.

Additionally, the Mezzanine could be configured to serve in an ad hoc non-hierarchical network, such as an HADR event. The Mezzanine's ability to support potentially any hardware or software, including differing types of Unicode (OS language), allows parties to bring and share native applications and sources to the collaboration sessions. Chapter II discusses the importance of growing trust among government, NGO, and other types of agencies as a facilitator for information sharing and removing collaboration difficulties among first responders. Using the Mezzanine has the potential to increase information sharing and interoperability among participants resulting in improved trust, which would have positive second order effects, such as increased community confidence, in first responders.

2. Given the Oblong Mezzanine capability, what factors need to be considered before deploying into an austere environment?

The Mezzanine was originally designed by Oblong Industries as a fixed system for the commercial sector, which provided organizations the ability to participate in visual collaboration over the Internet. The key take away is that most organizations integrate the Mezzanine into their organization's computer network, which has sufficient bandwidth. However, the expeditionary Mezzanine will be used in environments with limited organic network capabilities, thus requiring the operators to consider several factors prior to deploying to an austere environment:

- **Bandwidth capacity:** According to Oblong technical documentation, the Mezzanine requires at least15Mbps for upload and download (Oblong Industries, 2014b).

- **Latency:** The technical documentation for Mezzanine states that the latency between devices shall not exceed 300ms round trip (Oblong Industries, 2014b). As discussed in Chapter IV, this study witnessed an average latency of approximately 835ms while utilizing a satellite-based ISP, which far exceeds the stated maximum latency.

- **VPN Overhead:** The system does not currently support NAT, and the Mezzanine requires connection to a routable subnet. This requires operators to ensure the system is on a routable subnet where NAT is not required (Oblong Industries, 2014b). This setup has the potential to add 40 to 50 percent of additional overhead, and must be considered when working in lower bandwidth networks

- **Weight:** The expeditionary Mezzanine weighs in at approximately 1605lbs as discussed in Chapter IV. Also discussed in Chapter IV, the average weight restrictions of the top five U.S. airlines is between 50 and 100 pounds (Alaska Airlines, 2016; American Airlines, 2016; Delta

Airlines, 2016; Hawaiian Airlines, 2016; United Airlines, 2016). This adds additional logistical requirements and complexity with deploying the system.

3. What possible future mission(s) does Oblong Mezzanine enable?

The Oblong Mezzanine system is an emerging technology in visual human collaboration. In the past decade, communication meant the exchange of information, and email or phone calls were sufficient. However, organizations are looking to bring back the human engagement characteristic during the exchange of information, which improves communication. The Mezzanine enables human interaction from anywhere to anywhere by using immersive telepresence. The immersive collaboration characteristics of the Mezzanine potentially support several future missions:

a. Special Operation Forces

With Mezzanine supporting almost any mobile or mounted device and multiple users, the system could enable units operating independently to share information rapidly over commercial networks. Stanley McChrystal, U.S. Army General (retired) discussed VTC sessions with thousands of participants in his book *Team of Teams*. While in Iraq, he discovered multiple small teams of Special Operation Forces (SOF) working in isolation and independent of one another against a force that was connected (McChrystal, 2015). Although General McChrystal was ultimately successful removing the military hierarchy that was preventing sustained success, it involved a complete reversal of conventional organizational roles, authority, leadership, and collaboration methods. With respect to this situation, the Mezzanine system could have allowed the units to come together forming a single network to communicate, coordinate, and operate as a team, without a complete change of organizational structure and processes.

b. Intelligence, Surveillance, and Reconnaissance

The ability of the Mezzanine to display multiple data ingests including streaming video provides a means to increase situational awareness of operators by allowing them to monitor multiple Intelligence, Surveillance, and Reconnaissance (ISR) ingests. That is, the Mezzanine would enable analysts to almost fuse key information on the fly. Such fusion is always a challenge in operations. The enhanced capabilities of the Mezzanine enables and creates opportunities to realize holistic battlespace awareness.

- Real-time Data Analytics: The Mezzanine enables multiple users to connect to a session from any device that has Internet access. The session can include subject matter experts to conduct real-time analysis of data from multiple sources. The MzReach software client allows the session to take place, and provides the ability for mobile devices to connect without hardware or software constraints. This will allow organizations to save time and money and align business and intelligence data.

- Sensor Streaming Analysis: Unmanned systems usage is increasing in the U.S. military. These platforms are providing a multitude of data feeds at any given time. The Mezzanine could feasibly ingest multiple feeds in real-time from multiple UxV systems. This could reduce operator load and equipment needed while increasing mission effectiveness.

c. Field Medical Collaboration

Deploying an expeditionary Mezzanine with a hospital ship could vastly increase collaboration among military and local physicians while providing state-of-the-art visual tools for medical professionals to assess patient cases and determine best treatment plans. A possible example would be the USNS *Mercy*, a Navy hospital ship, which conducts periodic deployments to the Far East as part of the Pacific Partnership operations. Mezzanine operators could easily setup collaboration sessions among physicians, clinical leaders, and specialists to share expertise. Additionally, the systems can bridge the gap between military, NGO, coalition partners, and the indigenous population increasing information sharing, partnership, and trust.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

This thesis focuses on describing the concepts and technologies associated with distributed collaboration and working in austere environments. Further research is required in order to continue the refinement of the Mezzanine software and processes to allow the system to operate in DIL and low-bandwidth tactical networks. From the evaluations, it was determined that the present Oblong Mezzanine requires high-bandwidth network connectivity to function as designed, creating challenges using the system in tactical and DIL environments. However, there remains additional work to expand upon and verify work done with this thesis. Further research possibilities include:

a. Further Field-Testing

The evaluations were limited in nature due to not having availability of the satellite equipment and other Mezzanines during testing. Future research should focus on continued field-testing and identifying constraints associated with operating the system in austere environments. The system requires further testing of Mezzanine-to-Mezzanine and Mezzanine to other hardwired and mobile devices when communicating via satellite-based networks. One possibility is for the Marine Corps Tactical Systems Support Activity (MCTSSA) to analyze the interoperability with current tactical communication system within the Marine Corps, and then provide critical feedback of the system's performance. Finally, field-testing will also verify the sustainability and survivability of the Mezzanine equipment in a variety of geographic and meteorological conditions.

b. Weight Reduction

Chapter IV discusses the current weight of the system and each component, and weight restrictions of the top five commercial airlines being between 50 and 100 lbs. Each display and its associated ruggedized case, which doubles as the stand exceeds the weight restrictions of most commercial airlines. Work needs to be conducted to reduce the weight of the displays and cases. The inability to use commercial airlines for transit will add additional logistical requirements and potential cost to transporting the system. Reducing the weight of each piece to 100lbs. or under will provide easier logistics when deploying to areas not easily accessible to military aircraft or vessels. Perhaps the screens could be made much smaller, which would require smaller and lighter support stands and carrying cases. Additionally, future research could determine how many pallets the Mezzanine requires for military transport.

c. Live Language Transcription

Another area of possible research to explore is adding additional application software to incorporate real-time live language translation software to the Mezzanine.

The military and other agencies often find themselves working in multi-national environments with a convergence of many languages or dialects. Having a system with the ability to translate verbal communication in real-time could increase communication effectiveness resulting in better trust among organizations.

d. VPNs

As noted, the requirement to use VPNs actually prevented one of the experiments from being completed. Further research is required to explore different options for approaching this challenge. Many networks have all sorts of operating restrictions designed to improve security, but they often hamper the use of collaboration tools. There must be a better and more consistent approach that aligns with most of the world's general information technology (IT) operating practices.

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